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FEASIBILITY STUDY
ASCS REMOTE SENSING/COMPLIANCE
DETERMINATION SYSTEM
FINAL REPORT

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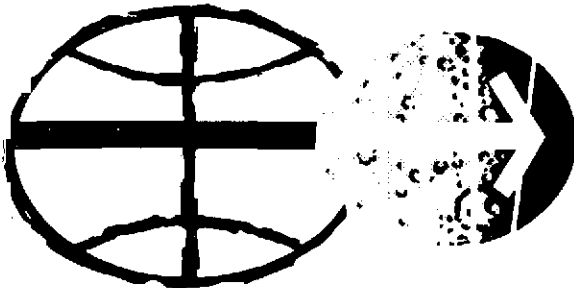
Prepared by

Lockheed Electronics Company, Inc.
Houston Aerospace Systems Division
Houston, Texas

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for

EARTH OBSERVATIONS DIVISION



MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

January 1973

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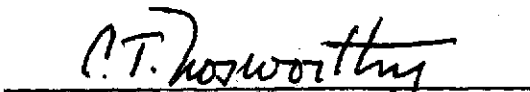
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PREPARED BY


I. E. Duggan


T. C. Minter, Jr.



B. H. Moore



C. T. Nosworthy

APPROVED BY

LEC

NASA


R. E. Tokerud, Manager
Earth Observations Department


T. H. Smith, Jr.
EOD/ASCS Project Manager

Prepared by
Lockheed Electronics Company, Inc.

For

Earth Observations Division

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SUMMARY

A short-term technical study was performed by the MSC Earth Observations Division to determine the feasibility of the proposed Agricultural Stabilization and Conservation Service (ASCS) Automatic Remote Sensing/Compliance Determination System. For the study, the term "Automatic" was interpreted as applying to an "Automated" remote-sensing system that includes data acquisition, processing, and management. The conclusions drawn from the three study areas are summarized as follows.

Data Acquisition

The stated ASCS data acquisition objectives require broad spectral information for crop and land-use classification, high resolution for acreage measurements, and geometric fidelity for mapping and registration.

The stated ASCS objectives can be accomplished within the desired time frame (1980) by combining multispectral scanners and photographic sensors in high-altitude aircraft. The proposed solution will accomplish the required area coverage with greater operational economy. Cameras may possibly meet the ASCS requirements, although this conventional photographic sensor approach requires additional research prior to any final commitment. If spacecraft platforms and sensors are to be used for an ASCS program, data acquisition capabilities and ASCS requirements must be examined in more critical detail.

If space systems are to be considered, two interdependent problems will require additional research: developing

an advanced state-of-the-art operational spacecraft sensor, and determining the resolution necessary to satisfy the present ASCS Administrative Variance requirements. Aircraft and spacecraft acquisition subsystem requirements would become more tractable if the ASCS Administrative Variance requirements were less stringent.

Data Processing

The large volumes of data collected for the ASCS Automatic Remote Sensing/Compliance Determination System will be subjected to a succession of manipulations. Existing general purpose computers will not be able to fulfill the complete data processing needs in a timely and cost-effective manner, because of the short turnaround requirements specified by the ASCS.

Parallel digital or hybrid computers appear to offer the better potential of meeting the short turnaround requirements of ASCS. A complete data processing subsystem can be developed within the ASCS time limitations (by 1980) with the proper resources.

Data Management

The ASCS data management requirements are technically attainable by improvising existing information management techniques and systems within the provided resources.

CONTENTS

Section		Page
1.0	<u>INTRODUCTION</u>	1
	1.1 BACKGROUND.	1
	1.2 FEASIBILITY STUDY PLAN.	3
2.0	<u>STUDY RESULTS.</u>	15
	2.1 DATA ACQUISITION.	15
	2.1.1 Introduction.	15
	2.1.2 Identification of the Data Acquisition Subsystem Critical Parameters.	16
	2.1.3 Study 1	23
	2.1.4 Study 2	24
	2.1.5 Study 3	26
	2.1.6 Instantaneous Field-of-View Requirements.	29
	2.1.7 Further MSS Performance Parameters.	30
	2.1.8 Cameras	33
	2.1.9 Analyses of the Data Recording Critical Parameters	36
	2.1.10 Additional Critical Parameters.	39
	2.2 DATA PROCESSING	42
	2.2.1 Introduction.	42
	2.2.2 Data Processing Requirements.	42

Section		Page
	2.2.3 Data Processing Subsystem . . .	49
	2.2.4 Data Processing System Parameters.	54
	2.2.5 Data Correlation and Registration.	55
	2.2.6 Training Field Selection, Feature Selection, and Pattern Classifiers	63
	2.2.7 Boundary Detection.	81
	2.2.8 Mensuration	85
	2.2.9 Computer Systems and Data Storage Requirements.	87
	2.2.10 Automatic, Semiautomatic, and Manual Classification Systems	94
2.3	DATA MANAGEMENT	103
	2.3.1 Data Base for Tract Location and Sensor Data Registration. .	103
	2.3.2 Data Storage and Retrieval and Data Volumes.	106
3.0	<u>DISCUSSION</u>	109
3.1	CONCLUSIONS	109
	3.1.1 Data Acquisition.	109
	3.1.2 Data Processing	110
	3.1.3 Data Management	111
3.2	RECOMMENDATIONS	112
	3.2.1 Data Acquisition.	112

Section		Page
	3.2.2 Data Processing	113
	3.2.3 Data Management	114
	3.2.4 SR&T and In-House MSC Research and Development (R&D) Programs.	115
4.0	<u>REFERENCES</u>	119
5.0	<u>BIBLIOGRAPHY</u>	123

FIGURES

Figure		Page
1.1	Step 1	4
1.2	Typical scene.	10
1.3	Study parameters	12
1.4	Prototype ASCS system.	14
2.1	MSS design parameters.	17
2.2	Distribution of corn, sorghum, and barley field sizes in the states of Ohio, Indiana, and Illinois.	21
2.3	Allowable boundary location errors to meet ASCS Administrative Variance	23
2.4	Pixel size required to meet Administrative Variance, study 1.	25
2.5	Pixel size required to meet Administrative Variance, study 2.	27
2.6	Scanner resolution requirements (in milliradians).	31
2.7	Camera resolution requirements (in line pairs/mm).	35
2.8	Data acquisition rates	38
2.9	Data storage rates (remote).	40
2.10	Typical scene.	43
2.11	Prototype ASCS system, showing data processing subsystems (shaded boxes)	50
2.12	A detailed breakdown on the elements of the data processing system	51
2.13	Clustering training field data	66

Figure		Page
2.14	Seasonal response calendar	67
2.15	Relationship between divergence and the probability of correct classification. . . .	70
2.16	Feature selection timing chart	74
2.17	Average performance by class	75
2.18	Graph showing accuracy of cover-type classification using the maximum likelihood classifier for test samples representing a 500-square-mile area	78
2.19	Total number of resolution elements in 300,000 square miles	91
2.20	CPU times for various resolution element sizes.	92
2.21	Tapes or mass storage units required to store a single overflight of the Corn Belt.	93
2.22	Montgomery County, Indiana, and the coverage of one RC-8 camera frame	97
2.23	Temporal analysis area in Montgomery County, Indiana.	98
2.24	Data registration.	105
2.25	Basic sensor parameters and data output volumes for surveying ASCS areas	107

TABLES

Table		Page
2-I	H. DELL FOSTER DIGITAL RECORDER MENSURATION EXERCISE	86
2-II	TEMPORAL CROP CLASSIFICATION - SEGMENT 212.	100
2-III	POTENTIAL CLASSIFICATION AREAS	102
2-IV	TIME ESTIMATES FOR CROP CLASSIFICATION . . .	102

1.0 INTRODUCTION

1.1 BACKGROUND

In May 1972, the Earth Observations Division (EOD) established an Agricultural Stabilization and Conservation Service (ASCS) study team, with a representative from each EOD Branch, to evaluate the joint NASA-MSC/USDA-ASCS proposal, "Manned Spacecraft Center Proposed Development Plan and Initial Task Description for the Development of a Remote Sensing/Compliance Determination System for the ASCS," dated November 1971 (revised April 1972). The results of this evaluation led to a broad-based, 21-day study to determine the technical feasibility of developing an operational aerospace remote-sensing system for ASCS.

Briefly, the present ASCS compliance program consists of the following:

- The ASCS has the legal responsibility for determining compliance of individual farm producers with the production adjustment, price support, and conservation programs.
- Compliance is presently determined by ground surveys and aerial photography.
- ASCS must make some 3,600,000 determinations annually, involving about 200 million acres.
- ASCS checks 25 percent of the farms in its program for compliance each year.
- ASCS employs 9,000 full and part-time employees in its compliance program at an annual cost of \$14 million.

- ASCS makes annual payments to farmers of \$3 billion. These determinations serve as a basis for providing several billion dollars more in commodity loans to farmers, and for establishing about \$5 million in farm commodity allotments and bases annually.

The ASCS objective is to develop an operational remote-sensing system for

- Automatic identification of specific crop species, land uses, and field boundaries.
- Accurate measurement of crop and land-use acreages.
- Automatic correlation of crop acreages and land uses to specific tracts and tract ownership.
- Rapid data dissemination to county agents.

A nationwide compliance system based on remote sensing is proposed. The system is to be implemented in five steps:

- Define requirements.
- Define the characteristics of the operational system, identify qualified techniques, and develop a prototype system by January 1976.
- Evaluate the prototype system by 1978.
- Refine the definition of the operating system, design the operational system, and initiate procurement by 1980.
- Implement the operational system by the mid-1980's.

NASA's primary objective in the project is to

- Define the prototype and operational parameters for data acquisition, processing, classification, and mapping systems.
- Evaluate existing data analysis techniques and measure their performance against overall system requirements.

NASA's role is limited primarily to step 1 of the development plan, which is shown in figure 1.1. NASA's role will diminish with the development of a prototype in 1976.

The basic questions answered in this study are

1. Can an automatic remote-sensing and compliance determination system be developed to satisfy ASCS objectives?
2. Will existing state-of-the-art technologies and information satisfy ASCS program requirements? If not, can technologies be developed to satisfy the program requirements?
3. Can the technologies be developed within the proposed time frame?
 - A prototype system by 1976?
 - An operational system by the early 1980's?

1.2 FEASIBILITY STUDY PLAN

Four study teams were formed to determine the feasibility of the proposed operational aerospace remote-sensing

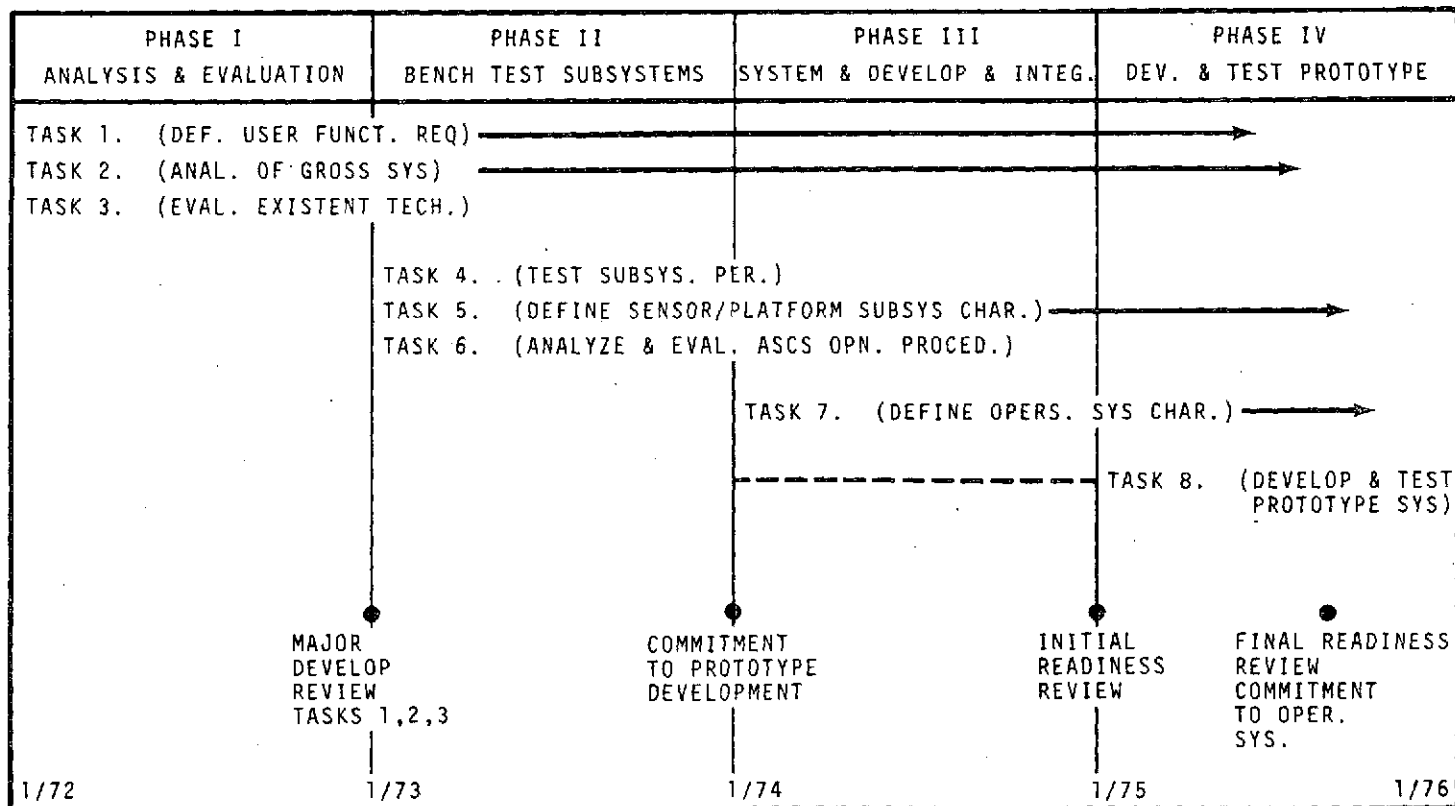


Figure 1.1 – Step 1.

system for ASCS. These study teams had broad representation from the various disciplines in remote sensing.

The guidelines provided for the study teams included User Program Requirements, User Information Requirements, the scope of ASCS requirements, a typical scene to be analyzed, a set of assumptions, and a set of study parameters. The guidelines are reviewed briefly.

The User Program Requirements are used to

1. Determine if the farmer has complied with set-aside acreage requirements. This involves determining that the farmer or farm operator has
 - Correct number of set-aside acres as permitted by ASCS and agreed upon by the participating farmer.
 - Met the set-aside acreage requirements by
 - a. Maintaining set-aside acreage in conserving uses, such as permanent or temporary grass covers, legumes, or wildlife habitats.
 - b. Protecting set-aside acreage against erosion and weeds.
 - c. Not grazing set-aside acreage during the five principal months of the growing season.
 - d. Disposing of harvestable crops by disposition date.
 - e. Planting certain "short supply" crops with ASCS approval.

- Placing land in set-aside acreage equal in productivity to average productivity of the farm.
- 2. Determine how many acres are planted to crops in the Production Adjustment Program. This information is used to determine bases and allotments.
- 3. Determine how many acres are in the conserving base. This acreage must be planted in permanent or rotation cover of grasses, legumes, wildlife food, or habitat cover. Land is placed in a conserving base to maintain crop bases.

The User Information Requirements are used to

1. Identify agricultural crops and land uses, with emphasis on those crops and land uses covered in the Production Adjustment Program; i.e., corn (discriminate between field corn and other types), grain sorghums (discriminate between sweet sorghums and sorghum-grass crosses), barley, wheat, oats, soybeans, cotton, alfalfa, clover, and other tame hays.

It is significant that not only the crops, but the manner in which they are used, are factors in determining farmer compliance with program provisions; i.e., harvested, cut for hay, left standing in the field for wildlife and/or erosion control, plowed or disced into the soil, pastured to the extent that the crop will not be harvested, and cut but not removed from the field. It is also significant under current programs whether or not the set-aside acreage (acreage removed from crop production and

on which payment is made to farmers) is equal in productivity to the average productivity of the cropland on the farm. (Data on soil types and productivity will be required.)

2. Measure the acreages of crops and land uses of fields and subdivisions of fields and/or tracts (contiguous areas of land under one ownership in the same county). An effort should be made to identify both planted and harvested crop acreages. Areas within fields and subdivisions of fields and/or tracts which are not planted to the crop being measured (drainage ditches, sod waterways, rock outcroppings, drouthy knobs, potholes, and turn rows) may be ignored, since the total acreage can be adjusted on an average percentage basis for areas with commonality of conditions. Currently, an Administrative Variance of 0.1 acre or 2 percent (not to exceed 0.9 acre) is provided in determining the acreage of a crop on a farm.
3. Relate crop and land-use data to coordinate positions. Crop and land-use data must be related to the appropriate position on the earth's surface so that data may be associated with tract and tract ownership. An accurate base is to be incorporated into the data system on which current remotely sensed data can be overlayed to provide a continuing or periodic update of that data base.

The feasibility of using either existing ASCS photography or new photography obtained at a more desirable scale will be considered in establishing a data base.

The size of the unit or cell to be used in the data base will be determined by consideration of a number of factors. These factors include resolution of the remote sensor, the success achieved in the identification and measurement of crop and land-use acreages, and the storage limitations in the central processors.

Data should be referenced to a field or subdivision of a field devoted to a specific crop or land-use, if this is achievable and economically feasible. The initial goal should be 25 meters in the absence of better information.

4. Develop effective data flow systems between county ASCS offices and the data center. The prototype data flow systems will be installed in selected county offices to interact with the data center. These county terminals and the data system will be designed to provide effective data flow (input capability, computer access, and the data retrieval) between the selected counties and the data center. These terminals will serve as prototype installations for concept evaluation before being expanded to a national system.

The scope of the ASCS requirements is to

- Apply the proposed remote-sensing system to a multistate area with approximately 300,000 square miles of cropland (200 million acres), the principal corn-and-wheat-producing states.

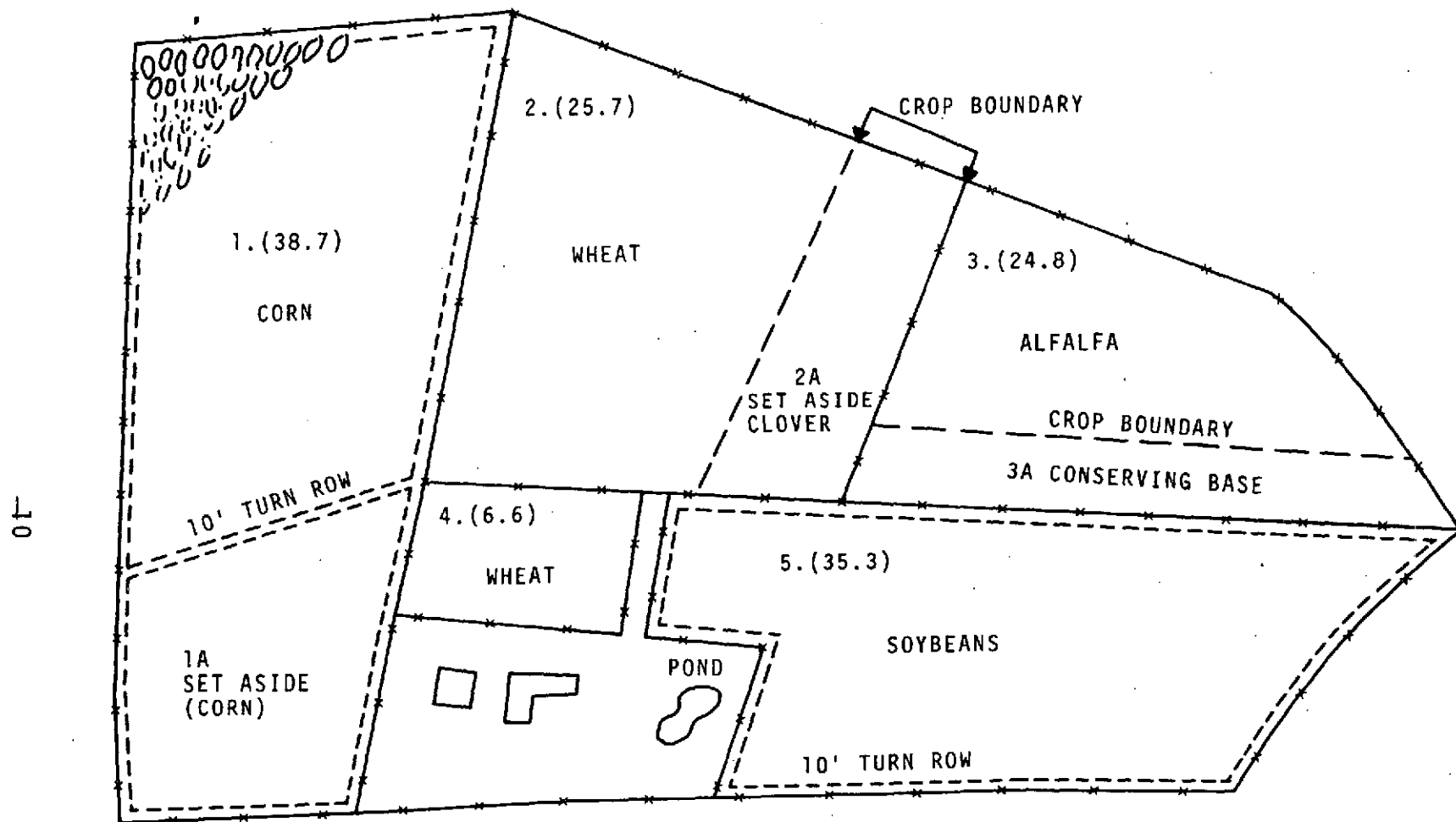
- Survey the total area four times annually; compliance will be determined on one-fourth of that area (75,000 square miles). These surveys will be largely completed by July 1 of each year, with some limited surveys to be made through August.
- Emphasize crops in the production adjustment program (feed grains, wheat, cotton).
- Complete 90 percent of compliance determinations by July 1 of each year.

Figure 1.2 shows the typical scene which the study teams were asked to consider.

The typical scene has several important characteristics which include:

- Crop Types
Corn, grain sorghums, winter wheat, barley, oats, soybeans, alfalfa, clover, and other tame hays, which are being grown or can be grown on the tract.
- Field Characteristics
Fields are usually enclosed by temporary and/or permanent boundaries. Areas such as turn rows, rock outcrops, and droughty areas may occur.
- Distribution
Corn and grains are the principal crops grown in Ohio, Indiana, and Illinois.

The guidelines for the study team included assumptions which were made based upon the study team's knowledge of



[Figure 1.2 — Typical scene. (Numbers in parentheses are areas in acres.)]

existing and future remote-sensing technology. The guidelines were further influenced by the condensed time period allocated for the study. The basic assumptions were

1. The remote sensing/compliance system had to be analyzed in terms of the *existing* documented ASCS program requirements.
2. The study parameters were based on the ASCS Administrative Variances stated in the MSC-ASCS proposal.
3. Land-use, e.g., set-aside acreage, will be a critical problem in the ASCS program. However, only the parameters stated in the ASCS proposal were considered: crop identification, boundary location, and acreage measurements. These three parameters address themselves to land-use in the next higher level of detail.
4. All *a priori* compliance data, both set-aside acres and conserving base, was prepared by ASCS using large-scale aerial photography to "map" farm fields and crops. More importantly, ASCS used field checks to actually measure fields.
5. For study purposes, the entire 300,000 square miles of the compliance area were to be covered for each mission; only 25 percent of the coverage would be manually or computer processed.
6. ASCS receives a computer listing of all farmers to be checked. From this listing, a random 25 percent are selected for field checks.

A set of study parameters was provided for the study teams. These parameters are shown in figure 1.3. The study

ALTITUDE		SENSORS		INFORMATION REQUIREMENTS*		FUNCTIONAL SUBSYSTEMS
250 NM		MSS RBV		CROP ID TO 98% ACCURACY		DATA ACQUISITION
60,000 FT		CAMERAS IR SCANNER MSS		BOUNDARY LOCATION TO ±2 FT		DATA PROCESSING
30,000 FT				ACREAGE MEASURE TO 98% ACCURACY		• PREPROCESSING • CLASSIFICATION • LOCATE BODY • MENSURATION • MAPPING
5,000 FT		OTHER**		LOCATION ACCURACY TO ±25 METERS		DATA MANAGEMENT

NOTES

*SINCE THIS STUDY, ASCS PERSONNEL HAVE INDICATED THAT THESE ADMINISTRATIVE VARIANCES MAY BE TOO SEVERE.

**NO CLASSIFIED SYSTEMS CONSIDERED.

Figure 1.3 – Study parameters.

teams were asked to consider the feasibility of achieving ASCS requirements from five different altitudes using a variety of sensors. Information processing requirements were established, and a functional description of the system is provided in figure 1.4.

Based on the guidelines, the study teams were asked to

1. Identify the critical parameter of each element (data acquisition, data processing, or data management).
2. Assess current state-of-the-art technology which will meet ASCS requirements for each of the critical parameters and determine required improvement or generation of new techniques.
3. Determine if existing and/or advanced technologies will meet ASCS program objectives and user data requirements.
4. Determine the ability of NASA-MSC to develop the capabilities to meet the program objectives and requirements within the proposed time frame.

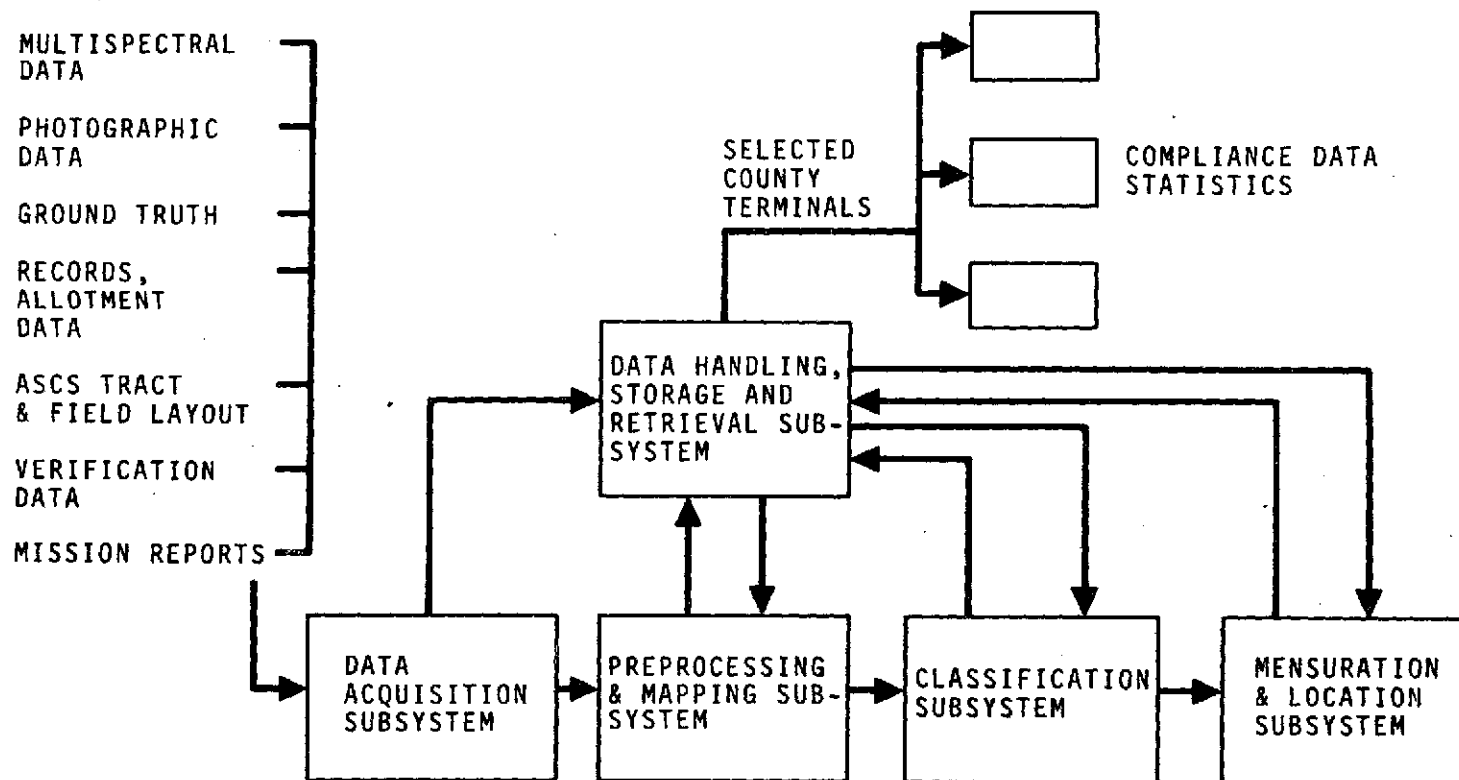


Figure 1.4 — Prototype ASCS system.

2.0 STUDY RESULTS

2.1 DATA ACQUISITION

2.1.1 Introduction

The data acquisition subsystem of the ASCS Automatic Remote Sensing/Compliance Determination System is composed of

- The sensors necessary to identify crops and land-use, to detect boundaries between different crops and land uses, and to measure acreages of specific crops and land uses.
- The remote data-recording systems necessary to keep pace with the data flow from the sensors and to store the data acquired from an aircraft flight of approximately 4 hours or a spacecraft's overpass.
- The airborne or spacecraft platform necessary to house, transport, provide power, stabilize sensors, and navigate to the required accuracy.

The study was simplified by considering only the critical parameters which were necessary to successfully assemble a realistic data acquisition system.

The data acquisition feasibility study results are organized sequentially.

1. The critical parameters of the data acquisition subsystem are identified.

2. The data acquisition critical parameter values are determined to satisfy ASCS requirements. These values were evaluated with respect to the state-of-the-art.

2.1.2 Identification of the Data Acquisition Subsystem Critical Parameters

2.1.2.1 Sensors.— The ASCS proposal stipulates a multispectral scanner (MSS) as the primary sensor, with some camera imagery as backup. This distinction was not made for the study, primarily because an "automatic" system essentially refers to the data processing techniques. While scanner output can be processed with a minimum of conversion steps to become computer compatible, camera imagery also can be rapidly digitized for computer processing. In addition, the basic qualities of the two kinds of sensors must be considered; multispectral scanners excel in gathering wide-range spectral information, while cameras excel in gathering spatial information.

2.1.2.2 Multispectral scanners.— The critical parameters for an MSS to meet ASCS requirements are contained within the design parameters. Designing an MSS involves a complex set of tradeoffs. Figure 2.1 shows the relationship between the major design parameters for which the system designer has options. The equations are not exact, but are intended to show the variations in signal-to-noise as a function of these major design parameters. The differences between the two equations for single versus multiple detectors occur primarily within the bracketed variables.

● SINGLE DETECTOR

$$SNR = H_T A_O \tau_O D^* \left[\left(\frac{\Delta\phi}{A_d} \right)^{1/2} \left(\frac{T_S}{\phi_T} \right)^{1/2} \right]$$

● MULTIPLE DETECTORS

$$SNR = H_T A_O \tau_O D^* \left[\frac{1}{F} \left(\frac{N}{\theta_T} \right)^{1/2} \left(\frac{T_S}{\phi_T} \right)^{1/2} \right]$$

● WHERE SNR = PEAK SIGNAL TO RMS NOISE RATIO

H_T = SCENE IRRADIANCE AT ENTRANCE APERTURE

τ_O = OPTICAL SYSTEM TRANSMISSION FACTOR

D^* = DETECTOR DETECTIVITY

A_O = AREA OF ENTRANCE APERTURE

$\Delta\phi$ = AZIMUTH INSTANTANEOUS FIELD-OF-VIEW

A_d = AREA OF DETECTOR

T_S = SCAN TIME

ϕ_T = AZIMUTH TOTAL FIELD-OF-VIEW

F = SYSTEM OPTICAL FOCAL LENGTH

N = NUMBER OF DETECTORS

θ_T = ELEVATION TOTAL FIELD-OF-VIEW

● EQUATIONS ARE FOR A BACKGROUND NOISE-LIMITED SYSTEM

Figure 2.1 - MSS design parameters.

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The derivations of these two equations can be found in standard texts on the subject, but terminology differs. A military standard on terminology is being written, but is not yet completed.

All the parameters listed on the right-hand side of the equation are variables available to the system designer.

- H_T -- scene irradiance; a function of the altitude between scene and sensor.
- A_O -- area of the entrance aperture determined by the scanning technique. When rotating mirrors are used, the physical limitations on the masses to be rotated limit aperture size.
- τ_O -- optical system transmission function; a lumped parameter containing effects such as reflective versus refractive optics and detector shielding.
- D^* -- detector detectability; must be selected from available detectors. Tradeoffs are also involved, such as spectral region, electrical band-pass, and cooling required.
- A_ϕ -- detector area; must be small for small $\Delta\phi$. It has to compete with diffraction limitations.
- $\Delta\phi$ -- azimuth instantaneous field-of-view (IFOV); a function of detector size plus any stops and system focal length.
- T_s -- scan time of a single scan line; a function of $\Delta\phi$, ϕ_T , forward motion, number of detectors, and desired scan-line overlap.

- ϕ_T -- azimuth total field-of-view; depends on desired coverage for a single pass over the scanned terrain and is limited by the techniques available to correct for scan angle effects, both in the instrument and in the scene scanned.
- F -- system optical focal length; has physical limitations. Tradeoffs exist between fast systems and $\Delta\phi$ requirements.
- N -- number of detectors; can be quite large, but each detector has its own preamplifier, and detectors may vary in output.
- θ_T -- elevation total field-of-view; the scan angle in the direction of the flight line, determined by N.

From the equations in figure 2.1, numerous tradeoffs obviously can and must be made in the construction of an MSS for the proposed ASCS project. These MSS performance equations apply to linear, object plane-scanning perpendicular to the flight line, with one or more detectors with their IFOV's distributed along the direction of the flight line. Other scanning techniques are available, such as circular or conical, and different equations would be required.

In summary, for a linear, object plane-scanning MSS, the design parameter most critical to the ASCS project is the IFOV. The IFOV projected on the ground from some altitude gives the instantaneous imaged spot size, called pixel

element. The size of the pixel is critical to meeting the ASCS objectives and is discussed in the following paragraphs. The remaining parameters must be adjusted for compatibility with IFOV requirements.

2.1.2.3 Analyses of the required instantaneous ground resolvable area.— The required resolution spot size on the ground, called pixel size, from which MSS IFOV is determined was not known from the available literature. Two ASCS requirements are affected by the pixel size: crop and land-use identification and boundary detection for area measurements. The more stringent is boundary detection.

The first step in determining the required pixel size was taking sample data for the distribution of some grain field sizes in the U.S. Corn Belt (fig. 2.2). It is significant that the histogram shows a large portion of the fields are in the 1- to 10-acre range. Next, an analysis was made of the allowable errors in locating a field's boundaries. Since the boundary positions are used to determine the enclosed acreage, the allowable boundary location errors are determined from the allowable acreage errors. For the ASCS Administrative Variance limits, these allowable errors are 0.1 acre or 2 percent, whichever is greater, not to exceed 0.9 acre. The results of the analysis are shown (fig. 2.3) for a rectangular field with a 1 by 5 aspect ratio.

Figure 2.3 shows that below 5 acres the error boundary is 0.1 acre, and for 5 to 45 acres it is 2 percent. Above 45 acres, the 0.9 acre error boundary dominates.

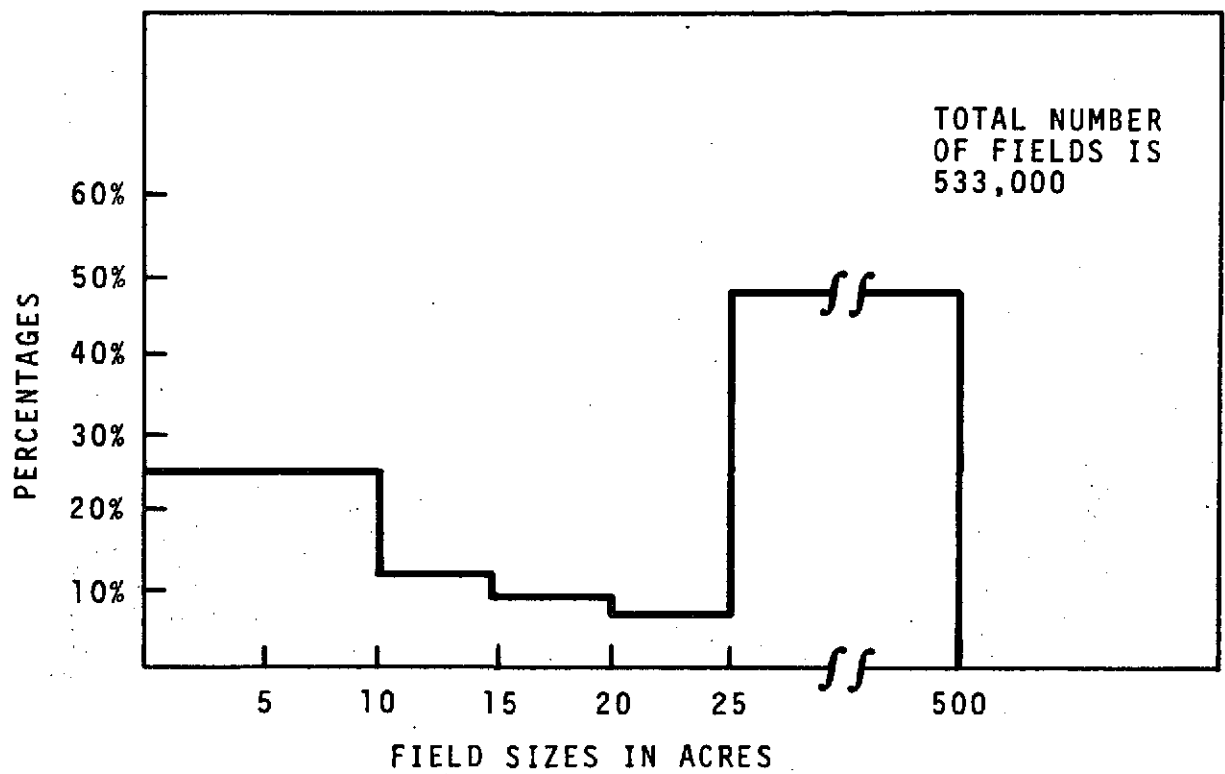


Figure 2.2 — Distribution of corn, sorghum, and barley field sizes in the states of Ohio, Indiana, and Illinois.

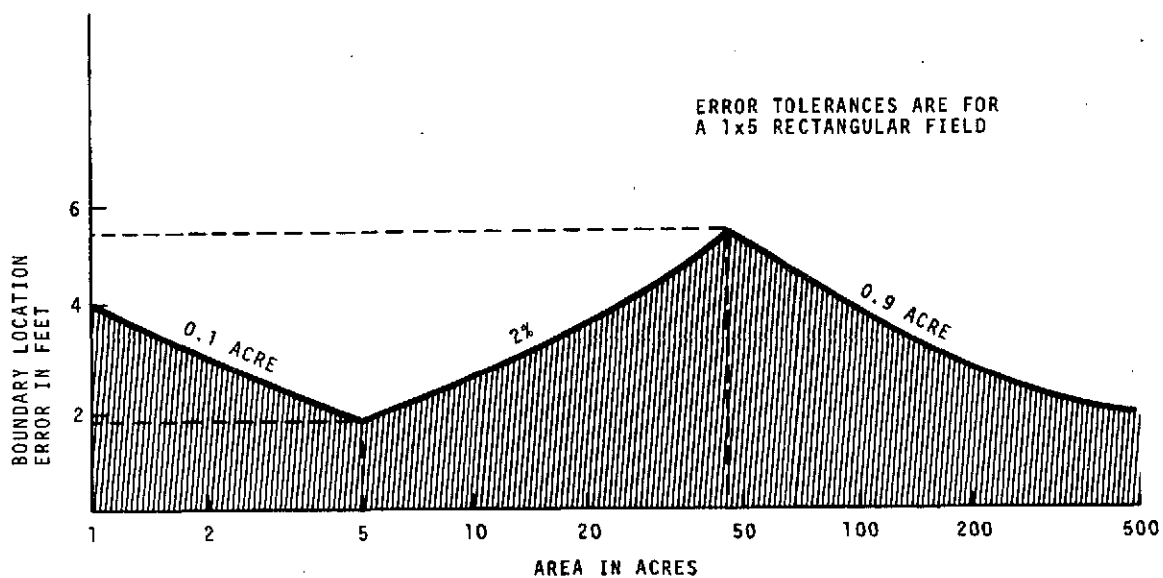


Figure 2.3 — Allowable boundary location errors to meet ASCS
Administrative Variance.

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The minimum boundary location error of ± 2 feet occurs at 5 acres, and beyond approximately 500 acres the allowable error decreases from ± 2 feet and approaches zero asymptotically. For field areas distributed squarely, the allowable boundary location errors are not as severe (± 3 feet for 5 acres). For area distributions greater than 1 by 5, however, the allowable errors are more severe. This is also true for circular fields, where the allowable boundary location error is ± 2 feet for a 5-acre field. It was decided that the ± 2 -foot allowable boundary location error represented a working "worst case" and was selected for the remainder of the resolution analysis.

With a ± 2 -foot acceptable error in boundary location established, three separate studies were undertaken to determine the largest pixel size allowable. The largest pixel size was sought because the smaller the pixel, the smaller the MSSIFOV and the more severe the MSS design criteria. The three studies are designated Study 1, 2, and 3, and the results are presented sequentially because of the different conditions set forth in each case.

2.1.3 Study 1

Problem to be analyzed: For a sharp boundary between two differing crops with typical values of contrast and a finite square pixel crossing the sharp boundary, can the position of the sharp boundary within the finite pixel be determined? If not, can a boundary location gain be achieved by overlapping pixels (equivalent to a higher data acquisition rate)?

Conditions:

1. Contrast ratios
 - grass/corn 1:1.5
 - wheat/loam 1:1.25
2. Sufficient sensor sensitivity to record irradiance differences arising from these contrast ratios.
3. A step function between the irradiance levels from the two adjoining fields.
4. A scan line consisting of contiguous pixels crossing the boundary at right angles.
5. Fifty percent pixel overlap, if necessary.

Results:

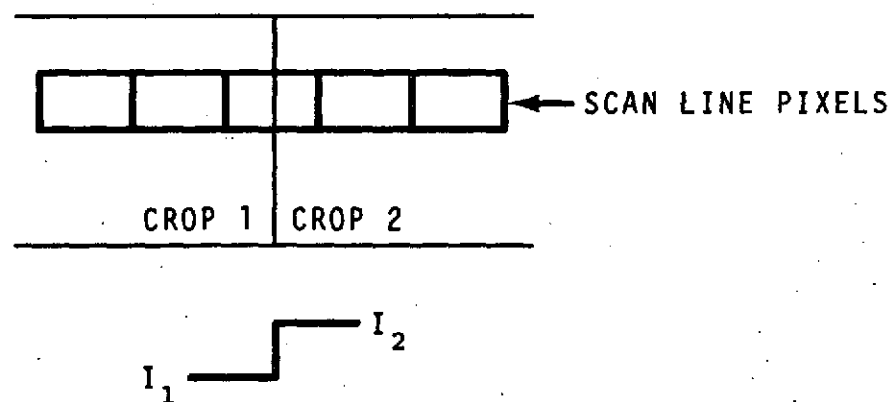
1. The uncertainty of the location of a sharp boundary within a finite pixel element is equal to the size of the pixel.
2. On the average, nothing is gained by a 50-percent pixel overlap.

The results of Study 1 are summarized in figure 2.4.

2.1.4 Study 2

Problem to be analyzed: Rather than restricting boundary detection pixel requirements to one boundary crossing, consider that multiple boundary crossings will occur when a typical field is scanned. Using realistic values for scene and sensor characteristics, determine the effects of pixel size on measuring the acreage of a typical field.

- ± 2 FT BOUNDARY DETECTION REQUIRED



STUDY-PRODUCED RESULTS:

- 1 THE UNCERTAINTY OF THE POSITION OF A BOUNDARY WITHIN A PIXEL IS EQUAL TO THE SIZE OF THE PIXEL
- 2 NOTHING IS GAINED BY A 50% PIXEL OVERLAP

Figure 2.4 - Pixel size required to meet Administrative Variance, study 1.

Conditions:

1. A field 500 by 1000 feet (approximately 12 acres).
2. A contrast between the field and its surroundings, on all four sides, of 1.3:1.
3. An MSS with a signal-to-noise ratio roughly that of the ERTS-1 MSS; $S/N = 35$. MSS data remains in analog form.
4. A pixel element 10 by 10 feet.

Results:

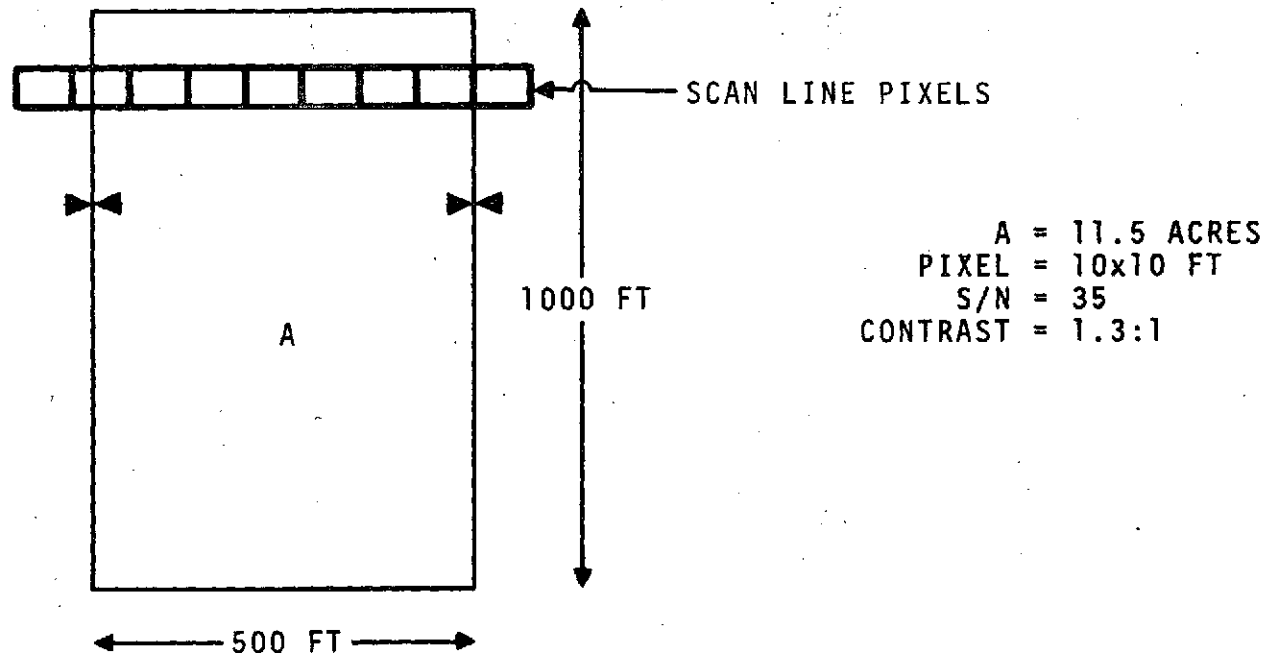
1. Acreage measurement will be within ± 0.1 percent 99 percent of the time for a 10- by 10-foot pixel.
2. Scan lines crossing the field at right angles may increase the error by one scan line. The quantitative effects were not determined.
3. It would be advantageous to plan flight lines so that fields are, in general, not crossed at right angles.

The results of Study 2 are summarized in figure 2.5.

2.1.5 Study 3

Problem to be analyzed: Since it is difficult to theoretically determine required pixel size, approach the problem in the reverse direction. Specifically, take some real data acquired by an MSC camera, digitized and analyzed by EOD and produced in imagery format, and physically measure the acreage of several fields from the digitized imagery.

ANOTHER STUDY PRODUCED THESE RESULTS:



- THE MEASUREMENT OF ACREAGE WILL BE WITHIN $\pm 0.1\%$, 99% OF THE TIME, FOR A 10x10 FT PIXEL.
- SCAN LINES CROSSING FIELDS AT RIGHT ANGLES MAY INCREASE ERROR BY ONE WHOLE SCAN LINE.
- FLY FLIGHT LINE SO THAT HEADING IS NEVER EXACTLY N-S OR E-W.

Figure 2.5 - Pixel size required to meet Administrative Variance, study 2.

Determine the error involved and relate this to the equivalent pixel size contained in the digitized data which is determined by the digitizing spot size.

Conditions:

1. Zeiss color-IR imagery acquired from 60,000 feet of rice fields near Katy, Texas.
2. The color-IR imagery magnified and the acreage of 12 fields measured manually. Assume that the acreage measurements determined from the color-IR film were accurate.
3. The color-IR film digitized by a microdensitometer with a spot size corresponding to approximately a 50-by-50-foot pixel on the ground.
4. Pattern recognition performed on the digitized data and imagery reconstructed from the classified digital data.
5. The data from steps 3 and 4 used to approximate scanning the area of interest with an MSS having a 50-by 50-foot pixel size.
6. The 12 fields in step 2 measured manually on the reconstructed digitized imagery using a polar planimeter to determine their areas.

Results:

1. The average field size was 8.8 acres.
2. The average error in measurement of acreage from the reconstructed digitized imagery was 4.3 percent.
3. The average error in boundary location equivalent to a 4.3 percent acreage determination error was approximately ± 5 feet.

4. To meet the ASCS Administrative Variance requirements, the 8.8-acre average field falls in the 2 percent allowable error bracket and requires a boundary location error equal to or less than ± 3 feet.
5. Depending on the validity of the reasoning, a 50-by 50-foot pixel element yielding a 4.3 percent acreage determination error indicates that it is probably possible to meet the ASCS Administrative Variance requirements with a pixel size several times larger than the allowable boundary location error.

From this study it appears that a pixel several times larger than the most stringent allowable error will suffice. In the following sections where the resolution is an important factor, it was decided to choose a range of pixel sizes which would bracket the actual required pixel size. For this purpose, pixel values of 2 by 2 feet, 10 by 10 feet, and 20 by 20 feet were selected.

2.1.6 Instantaneous Field-of-View Requirements

From the previous section, it was determined that pixel sizes of 2, 10, and 20 feet square were required for analyses. The IFOV and the sensor altitude yield the pixel size according to the relation (approximate but very accurate for small angles),

$$x = h\theta$$

where

x = one side of the pixel

h = the height of the sensor in kilofeet

θ = the IFOV in milliradians

Figure 2.6 shows the IFOV's necessary to achieve the required pixel sizes from the four altitudes given. The tabular results are in milliradians. For reference, the ERTS-1 MSS IFOV of 0.086 milliradian brackets those IFOV's encompassed by the heavy lines. Achievable pixel sizes obtainable by an order of magnitude decrease in IFOV are shown by the dashed lines. It is of interest that a 20-foot pixel then becomes possible from 250 nautical miles.

It has been reported, but unsubstantiated, that it may be possible to achieve a 0.010 milliradian IFOV either now or in the near future, for unclassified MSS's. If this should prove to be true, the values of IFOV in figure 2.6 bounded by the heavy and dashed lines are possible. It should be stressed that no unclassified scanner is presently flying within anywhere near that IFOV.

2.1.7 Further MSS Performance Parameters

Several of the other performance parameters listed in figure 2.1 had to be determined, since they affect data acquisition and storage rates.

- Number of Channels

An estimate of the number of channels is made. Based on University of Michigan and Purdue University work with the MSS's, and taking into account the hypothesis

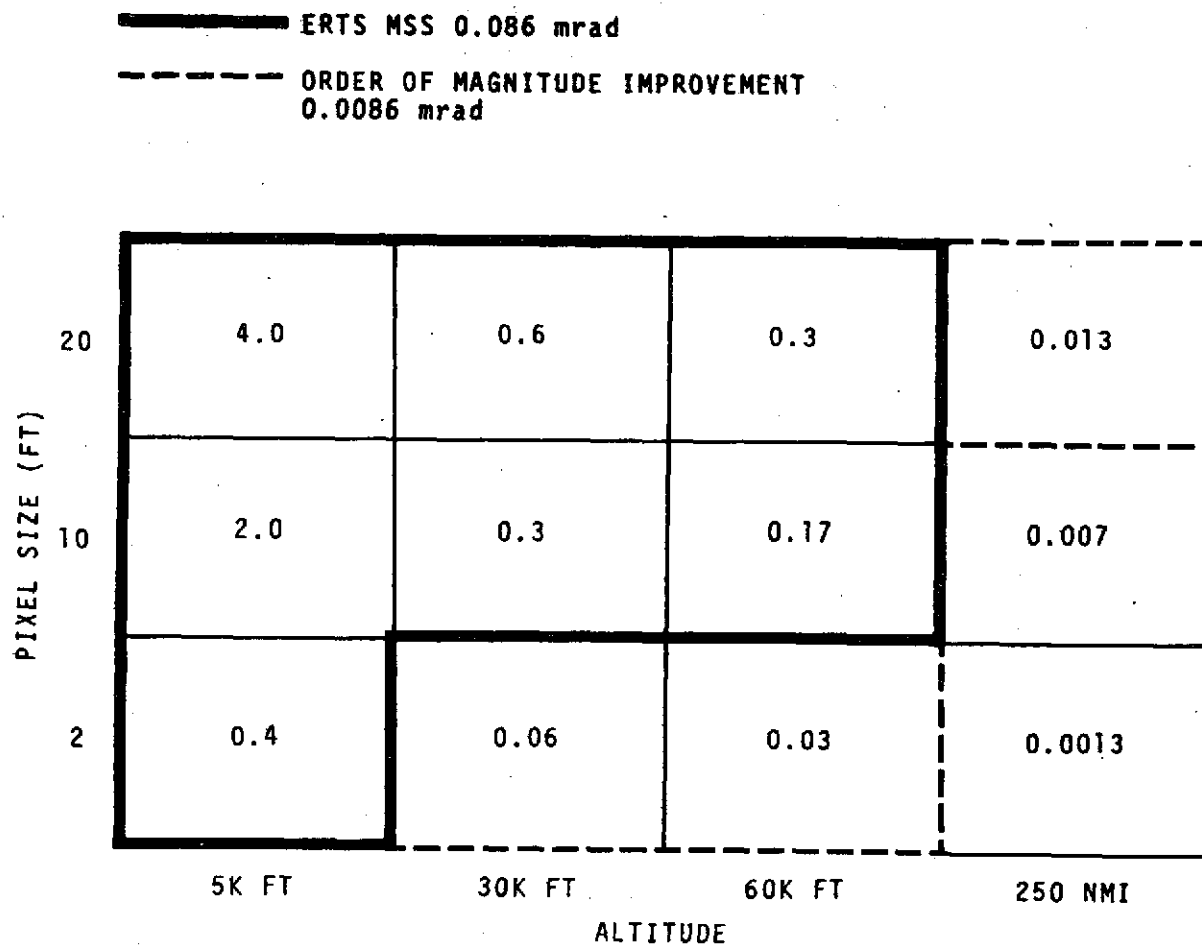


Figure 2.6 — Scanner resolution requirements (in milliradians).

that $n+1$ land uses can be identified with n spectral channels, about 10 channels seem to be sufficient. It is then possible to build an MSS with a set of collecting optics which acquire signals from a single scan line and internally separates the spectral information into 10 channels. This technique can lead to extremely high scan rates.

Alternately, techniques similar to the ERTS-1 MSS can be used. For example, for each spectral channel several detectors are aligned in the MSS image plane so that several scan lines are acquired for each channel simultaneously. While this technique slows the required scan rate, it increases the data acquisition rates. Further data will be given in the Data Acquisition section based on 10 channels with one detector per channel.

- Spectral Regions

The spectral wavelength positions and bandwidths for the 10 channels needed to meet ASCS requirements are not known at this time. NASA/MSR has an ongoing research program with a 24-channel scanner which covers the spectral region from visible to thermal infrared. Essentially, all the available atmospheric windows in these regions are utilized by the 24 channels. An analytical program could be generated by MSR to determine the best selection of channels for the ASCS project.

- Scan Method

Consideration should be given to various scan methods. Linear scanning at right angles to the flightpath is

a standard technique, but it complicates data correction because of the variations in atmospheric path and pixel size along the scan lines. Conical scanning maintains a constant atmospheric path and pixel size, but complicates data registration.

- Scan Angles

The scan angle determines the terrain coverage (swath width) along a flightpath. The larger the scan angle the larger the terrain coverage, but also the greater the data acquisition rate, atmospheric effects, and scan angle effects. For further analyses, linear scan angles of 60°, 80°, and 90° were selected for aircraft altitudes, and 10° and 20° for spacecraft.

2.1.8 Cameras

As mentioned previously, although the ASCS proposal suggests a camera system as the only backup to an MSS, this distinction was not made for the feasibility study. Primarily, this decision was based on analysis of the feasibility of achieving the ASCS objectives with any remote-sensing system which could do the job within the proposed time frame. Since camera systems enjoy a more advanced state of technological development than scanners, they should be considered candidates for the prime sensor system. Also, photointerpretive techniques are well developed and, if desired, camera imagery can be digitized, giving camera data reduction options of a variety of combinations of manual and automatic data processing. A camera system's ability to achieve high resolution counterbalances

its lack of wide spectral capabilities. Also, the most stringent ASCS requirement, which may be negotiable, will be area measurement at which camera imagery is proficient.

2.1.8.1 Camera resolution requirements.— The resolution attainable by a camera system is a function of several variables; lens resolution, film resolution, lens distortion, focal length, and system stability. An analysis was made of camera system resolution requirements in line pairs per millimeter to meet the 2-, 10-, and 20-foot pixel elements. The results are shown in figure 2.7. For the analysis, a focal length of 12 inches was selected to be typical of cameras flown at altitudes from 5,000 feet to 60,000 feet. It was decided to choose longer focal lengths for 250 nautical miles and to show the effects of doubling the focal length. For this purpose, 18- and 36-inch focal length results are shown on each side of a diagonal, with the upper right results for 18 inches and the lower left for 36 inches at 250 nautical miles. The 12-inch focal length at 250 nautical miles was considered inappropriate, since the required line pairs per millimeter resulting would be even greater than those shown.

To relate the results to state-of-the-art (fig. 2.7), resolutions claimed to be attainable by EREP S190A and B camera systems (according to the EREP Users Handbook) are enclosed within the solid dark lines. It is seen that all pixels can be achieved from 5,000 feet, 30,000 feet, and 60,000 feet, as well as the 20-foot pixel from 250 nautical miles using a 36-inch focal length system. Imagery collected by camera systems with resolutions greater than those

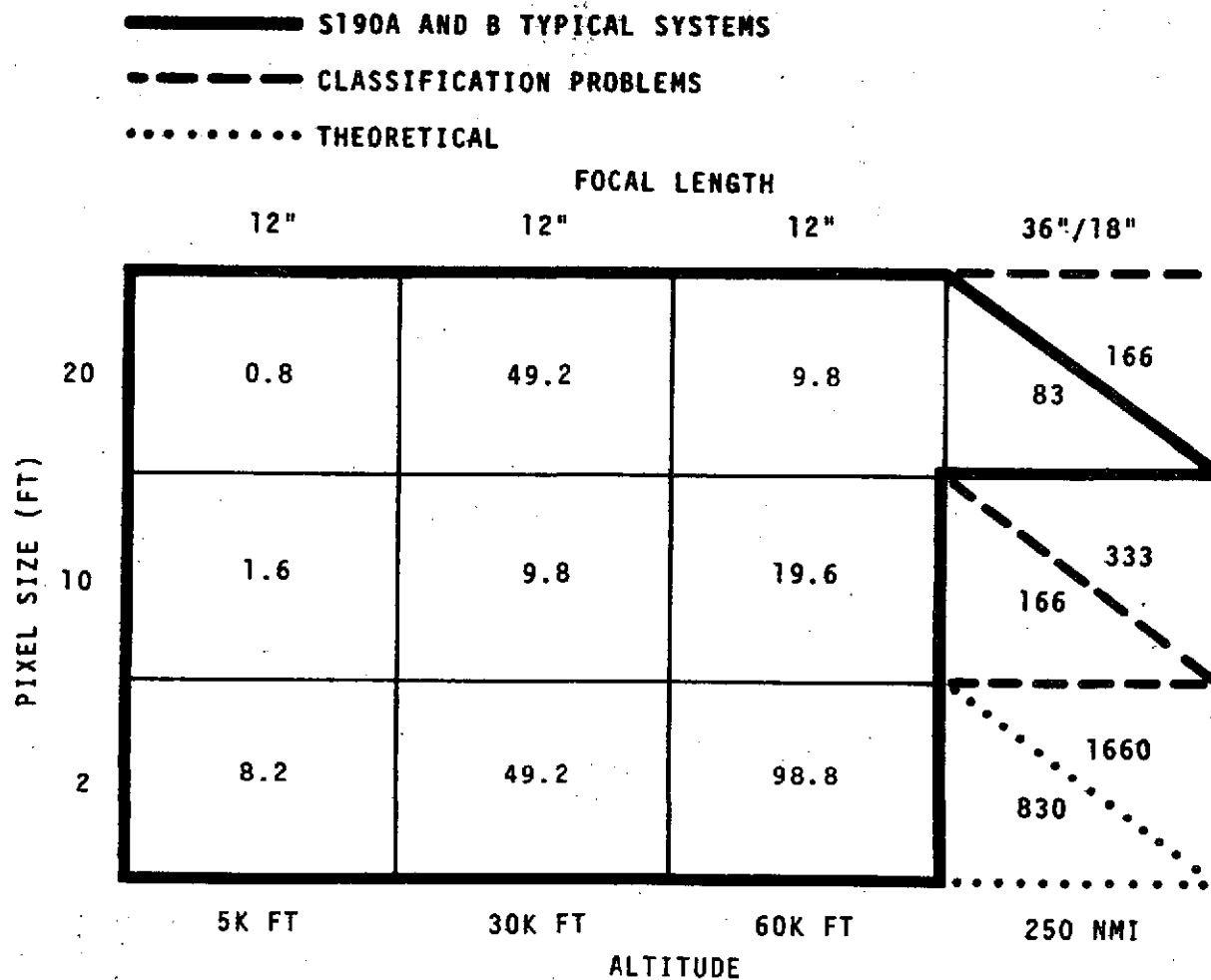


Figure 2.7 — Camera resolution requirements in line pairs/mm.

enclosed in the heavy lines is subject to security classification problems. Camera systems which theoretically could be built with state-of-the-art components should be able to achieve those additional line pairs enclosed in the dashed lines. Finally, the theoretical limit of camera system resolution would yield the additional line pairs enclosed in the dotted lines. The only line pair requirements not enclosed after these three classifications is that for a 2-foot pixel with an 18-inch focal length lens system.

The above discussion is based on the assumptions that image motion compensation is used, if necessary, and that the platform is stable.

Platform stability is an important factor in achieving high-resolution photography. A primary problem is platform vibration transmitted to the camera system, which can degrade the camera system performance. A given platform vibration level will set an upper limit on the camera system resolution achievable. This problem was not analyzed in detail, but must be considered in assembling a platform/camera system.

2.1.9 Analyses of the Data Recording Critical Parameters

The rates at which the sensors acquire data and the volumes of data required to be stored lead to limitations in the data acquisition subsystem. In general, the higher the sensor platform altitudes, the less space available for housing the sensor/data recording systems and the more costly space is per volume. The rate at which an MSS acquires data

is usually expressed as the bit rate and is defined as bits per second. The bit rate can be calculated based on the number of bits per word, the number of words per pixel, and the number of MSS channels. The data rate for cameras is usually expressed as the framing rate and is the number of frames per time necessary to achieve the required ground coverage and frame-to-frame overlap.

To estimate the data rates and volumes imposed on an Automatic Remote Sensing/Compliance Determination System, various conditions were postulated as follows:

- Two- to 20-foot pixels
- Altitudes of 5,000 feet, 30,000 feet, 60,000 feet, and 250 nautical miles
- Aircraft velocities of 180 mph at 5,000 feet, 240 mph at 30,000 feet, 375 mph at 60,000 feet, and a spacecraft velocity of 17,500 mph at 250 nautical miles
- One sample per pixel (contiguous pixels)
- One word per sample
- Eight bits per word

Results of the analysis of the data acquisition rates which a recording system must meet are given in figure 2.8. Scan angles of 60° and 90° are used for aircraft altitudes and 10° and 20° for a spacecraft at 250 nautical miles. The data rates are based on a per channel analysis, since the rate at which data is output from an MSS and received by a

THE RESULTS ARE GIVEN IN MILLIONS OF BITS/SEC ON A PER CHANNEL BASIS FOR A SCANNER COLLECTING ONE SAMPLE PER PIXEL, ONE WORD PER SAMPLE, AND EIGHT BITS PER WORD.

SCAN ANGLES PIXEL	60°	90°	60°	90°	60°	90°	10°	20°
2x2	3.1	5.3	24.4	42.2	76.1	132	1.4x10 ⁴	2.7x10 ⁴
10x10	0.12	0.21	0.98	1.7	3.04	5.3	550	1120
20x20	0.03	0.05	0.24	0.42	0.76	1.32	140	280
	5K FT		30K FT		60K FT		250 NMI	
	ALTITUDES							

Figure 2.8 — Data acquisition rates.

recorder is usually simultaneous for all channels. The information given in figure 2.8 shows that some extremely high data rates will be encountered at the higher altitudes with the smaller pixel sizes. Technically, these high rates do not present a problem, but it must be recognized that technical solutions to the question of high data rates may be impractical in design criteria.

The amounts of data collected on a typical flight were analyzed to determine if limitations on the proposed system would be imposed by data volumes collected. For this analysis, an MSS with 10 spectral channels and a 4-hour aircraft flight were used together with the same conditions in the data acquisition analysis. Figure 2.9 presents a condensed version of the results.

Again, the results do not present a technical limitation; however, for a systems designer the fact that an MSS with a 10-foot square pixel at a 60,000-foot altitude would fill an ERTS-1 type tape each 12 minutes shows that data storage requirements will impose system design restrictions.

2.1.10 Additional Critical Parameters

A number of additional data acquisition system parameters were considered, but either no definite conclusions could be drawn in the allotted study period or they were not considered to be technically critical. For instance, the proposal stipulates that a navigational location error of ± 25 meters must be met. For this problem, a number of potential solutions exist. The study team had no expertise

DATA IS GIVEN IN TRILLIONS (10^{12}) OF BITS/DAY ASSUMING A 4-HOUR TOTAL DATA ACQUISITION FLIGHT.

- STANDARD 15 INCH REEL $\rightarrow 15 \times 10^9$ BITS TOTAL
- ERTS-1 $\rightarrow 27.1 \times 10^9$ BITS/TAPE

		ALTITUDES					
		5K FT		30K FT		60K FT	
PIXEL (FT)	SCAN ANGLES	60°	90°	60°	90°	60°	90°
2x2		0.44	0.76	3.5	6.1	10.9	18.9
10x10		0.017	0.03	0.14	0.24	0.44	0.76
20x20		0.004	0.008	0.035	0.06	0.11	0.19

□ WOULD FILL AN ERTS-1 DATA TAPE EACH 12 MINUTES.

Figure 2.9 — Data storage rates (remote).

in this area, but discussions with some outside experts indicate that the U.S. Air Force possesses navigational techniques to meet error requirements much smaller than the proposed ± 25 meters.

2.1.11 References

The results presented in the Data Acquisition section are taken from LEC TM 642-529, "Data Acquisition Feasibility Study," by O. N. Brandt; LEC TM 642-568, "ASCS Study Relative to Computer Processing Loads," by W. P. Bennett; the ERTS Data Users Handbook; the EREP Users Handbook; and discussions with a number of technical persons.

2.2 DATA PROCESSING

2.2.1 Introduction

An automatic processing system was formulated based on the ASCS program requirements, ASCS user requirements, and a typical scene. Overall system performance parameters were defined and critical parameters were then identified for each element of the processing system. An assessment of the current state-of-the-art in technology was then made for each element of the system. Problem areas were identified, and efforts were made to identify new technique and needed improved technique requirements. The ability of NASA-MSC to develop these capabilities to meet ASCS program objectives and requirements within the proposed time frame was assessed.

2.2.2 Data Processing Requirements

The user program requirements outlined on page 5 of section 1.2 indicate that based on the overall user program requirements verification of land use on set-aside acres is the most important requirement. A typical scene, an example of which is shown in figure 2.10, has a number of important features which include:

- A variety of crops are grown on the tract, including corn, wheat, soybeans, alfalfa, clover, and unspecified vegetation on the conserving base acreage. Other crops that might be encountered in a typical scene are barley, oats, cotton, and tame hays. Native vegetation can be expected along fence rows. Trees and brush may be encountered in some areas of the tract.

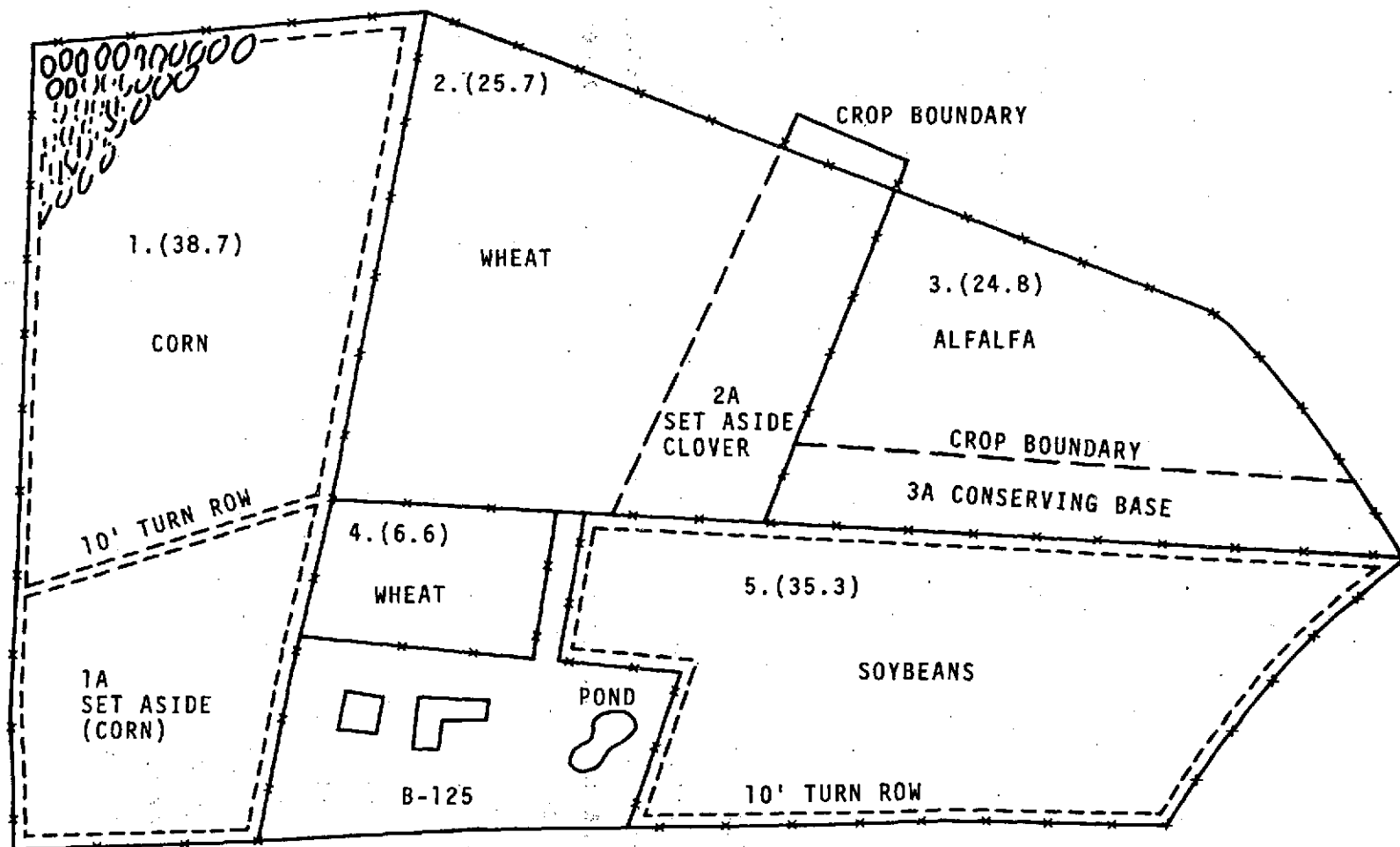


Figure 2.10 - Typical scene.

- The fields and subdivisions of fields in the typical scene have certain spatial characteristics. Each field or field subdivision is enclosed by temporary or permanent boundaries. A temporary boundary might be a line between two different crops or two different vegetations. A permanent boundary might be a fence or tree line. Crops may be planted in rows or broadcast.
- The boundaries of an agricultural crop are defined by the edge of the crop growth area. This will normally be temporary boundary unless the crop is grown up to a permanent boundary such as a fence or tree line.
- The boundaries of set-aside acreage and conserving base acreage are defined by permanent boundaries such as fences, or temporary boundaries such as a line between two different vegetations.
- Crop areas, set-aside acreage, and conserving base acreage may contain drouthy knobs, drainage ditches, sod waterways, rock outcroppings, potholes, and other unproductive areas.

The farm operator must provide the following information about a tract:

- The location of set-aside acreage, which will be designated on a photocopy of a photograph or on a form sketch [1]. An identification problem will result if the farmer moves the set-aside acreage to another area of the farm. In addition, the farmer will show on the photocopy any alternate crops, i.e., crops in short supply grown on

set-aside acreage, any harvestable crops to be planted on set-aside acreage which must be disposed of, and any small grains approved for conserving that are to remain standing on set-aside acreage after disposition date (also applies to conserving base acres).

- Disposition dates for all harvestable crops being grown on set-aside acreage.
- Acreages of wheat, feed grain, and upland cotton to receive history credit.
- The presence of crops such as soybeans, oats, barley, rye, and flax for statistical purposes.
- Any intention to harvest hay for storage from set-aside acreage.

For purposes of fully automatic data processing, the following suppositions were made about the typical scene.

- Each crop of interest to ASCS which appears in the typical scene has a spectral signature which is distinguishable from other crops, vegetations, or background signatures, e.g., native grass, trees, shrubs, bare ground, during some period of the growing season.
- For each crop or vegetation for which correct identification is essential to verification of compliance with ASCS requirements, a representative set of training fields are available from other parts of the flight line. This means that no crop of interest in the scene has a unique one-of-a-kind signature which only occurs once in the flight line.

- Only one type of crop or vegetation is grown within each crop boundary. A mixture of vegetations in one area could possibly result in a unique one-of-a-kind signature for which training fields are not available.
- The boundaries of a crop area are defined by the line between the crop and surrounding areas.
- The boundaries of set-aside acreage and conserving base acreage are defined by the edge of the proper land-use for these areas. This means that when measuring set-aside acreage, all of those acres in the set-aside and conserving base areas which comply with ASCS requirements for land-use in these areas will be used in computing set-aside and conserving base acreage. The boundaries of these areas will normally be permanent or temporary type boundaries.
- The aspect ratio of the fields (i.e., the ratio of the short dimension to the long dimension) is assumed to be approximately 1:5 or less on a 5-acre field; 1:50 or less on a 45-acre field; and 1:5 or less on a 500-acre field. This is conditioned on boundaries being located to within ± 2 feet.
- The locations of rock outcroppings, drouthy knobs, potholes, and drainage ditches which appear inside the boundaries of a field must be available prior to classification and mensuration on set-aside and conserving base acreage. Automatic location of these unproductive areas could be very difficult on set-aside and conserving base acreage if the unproductive area's boundaries are obscured by the intrusion of conserving vegetation such as permanent or temporary

grasses, clover, wildlife habitat food, or cover, into these areas.

- In determining land-use on set-aside and conserving base acreage, a set of signatures is assumed to be associated with each type of land-use. For example, a land-use such as maintenance of conserving vegetation is verified by the presence of a permanent or temporary grass cover, a legume, or a wildlife food or habitat on the acreage of a signature.
- Disposition of harvestable crops on set-aside acreage is to be verified by the presence of a signature from bare ground or stubble after disposition date.
- All fields for which mensuration is required are to be less than 500 acres in size.

Because of the size of the midwest Corn Belt, a large amount of variability can be expected in the farm tracts to be analyzed. As a result, a number of situations could arise which would cause some of the conditions stated above for automatic data processing to be violated. In these cases, either interactive (man-in-the-loop) and manual photointerpretation techniques or onsite checks will be required to establish adequate confidence levels in classification and mensuration. In addition, some farming practices, such as skip-row planting of crops, will require the use of manual interpretation techniques.

The following are some of the situations which may require the use of manual interpretation or onsite inspections:

- The signatures of crops or vegetation cannot be distinguished with the required accuracy classification techniques. A photointerpreter would use all available spectral, spatial, temporal, and texture information, along with any prior knowledge he may have about cropping practices, to achieve an acceptable confidence level in classification.
- The cover on a particular set-aside or conserving base area has a unique signature which cannot be identified or for which training fields were not available on the flight line. This might occur if a set-aside or a conserving base area vegetation cover is a mixture such as legumes, grass, and wildlife habitat.
- The boundaries of a crop area are not clearly defined or are obscured by the intrusion of weeds, disease, tree shadow, or cloud shadow into a crop area.
- Manual photointerpretation techniques or onsite inspections may be required to define the boundaries of unproductive areas, such as drouthy knobs, drainage ditches, or sod waterways, on set-aside and conserving base acreage.
- If the aspect ratio of a field-to-field subdivision is greater than approximately 1:5 on a 5-acre field, approximately 1:50 on a 45-acre field, or approximately 1:5 on a 500-acre field, manual measurement techniques using photography will be

required to achieve the mensuration accuracy required. This assumes that automatic techniques will only locate boundaries with an accuracy of ± 2 feet.

2.2.3 Data Processing Subsystem

Based on the data processing requirements, the typical scene, and the conditions set forth, a data processing system consisting of automatic, interactive (man-in-the-loop), and manual techniques is considered necessary and feasible. Figure 2.11 shows an overview of the system, while figure 2.12 gives a more detailed breakdown of the system elements and shows the data processing flow and system element relationships.

The steps in processing data as shown in figure 2.12 are:

- The typical scene receives illumination from the sun through a cloud-free sky near 12 noon (no shadows allowed). A multispectral scanner and a photographic camera record the scene through an intervening atmosphere. The information received at the sensor is recorded on magnetic tape and film.
- The multispectral scanner data undergoes a certain amount of raw data preprocessing (the data is placed in a computer-compatible format) and editing (such as for cloud cover). Film data is developed and rectified to take out terrain relief and other distortions to produce an orthophoto.
- The multispectral scanner data is correlated and registered to a reference image stored in the data

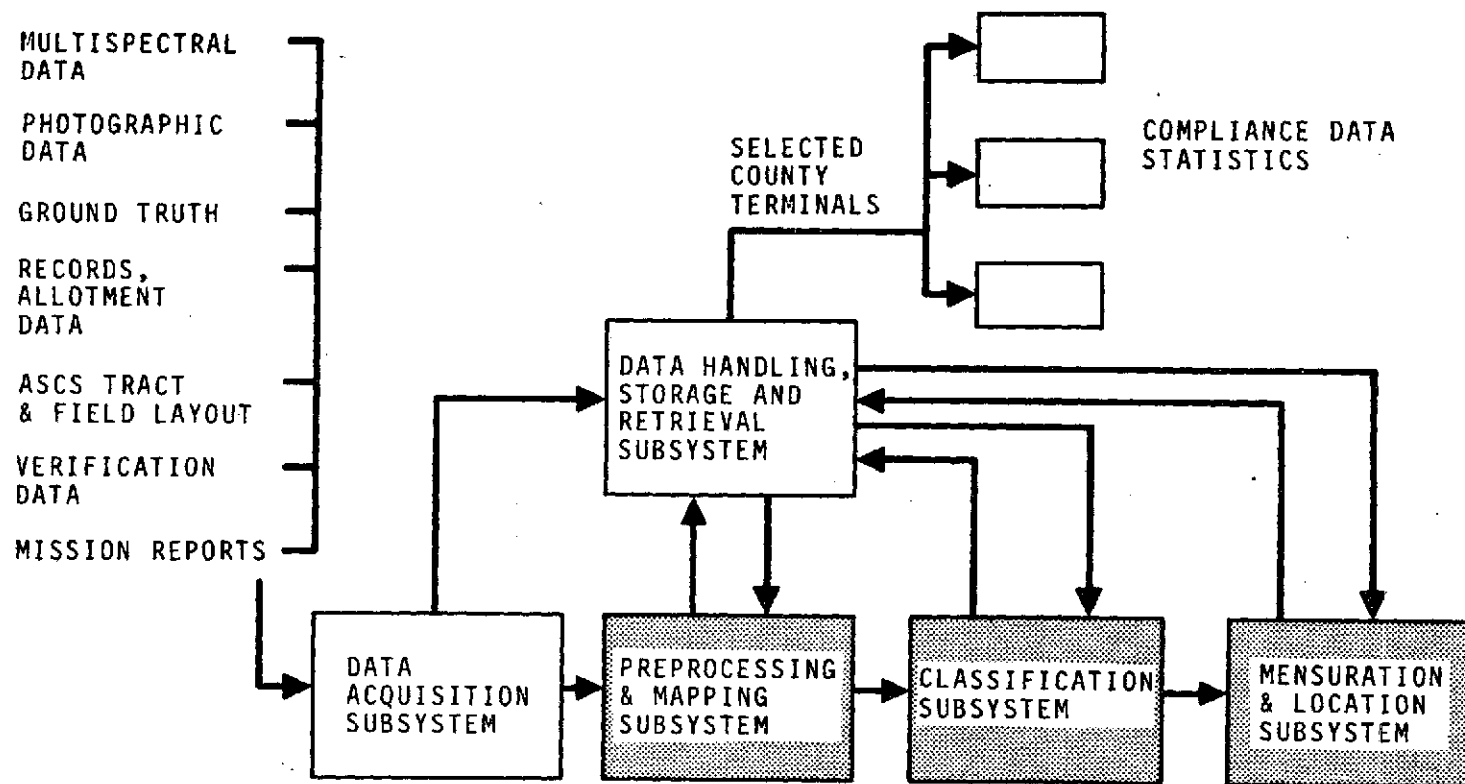


Figure 2.11 – Prototype ASCS system, showing data processing subsystems (shaded boxes).

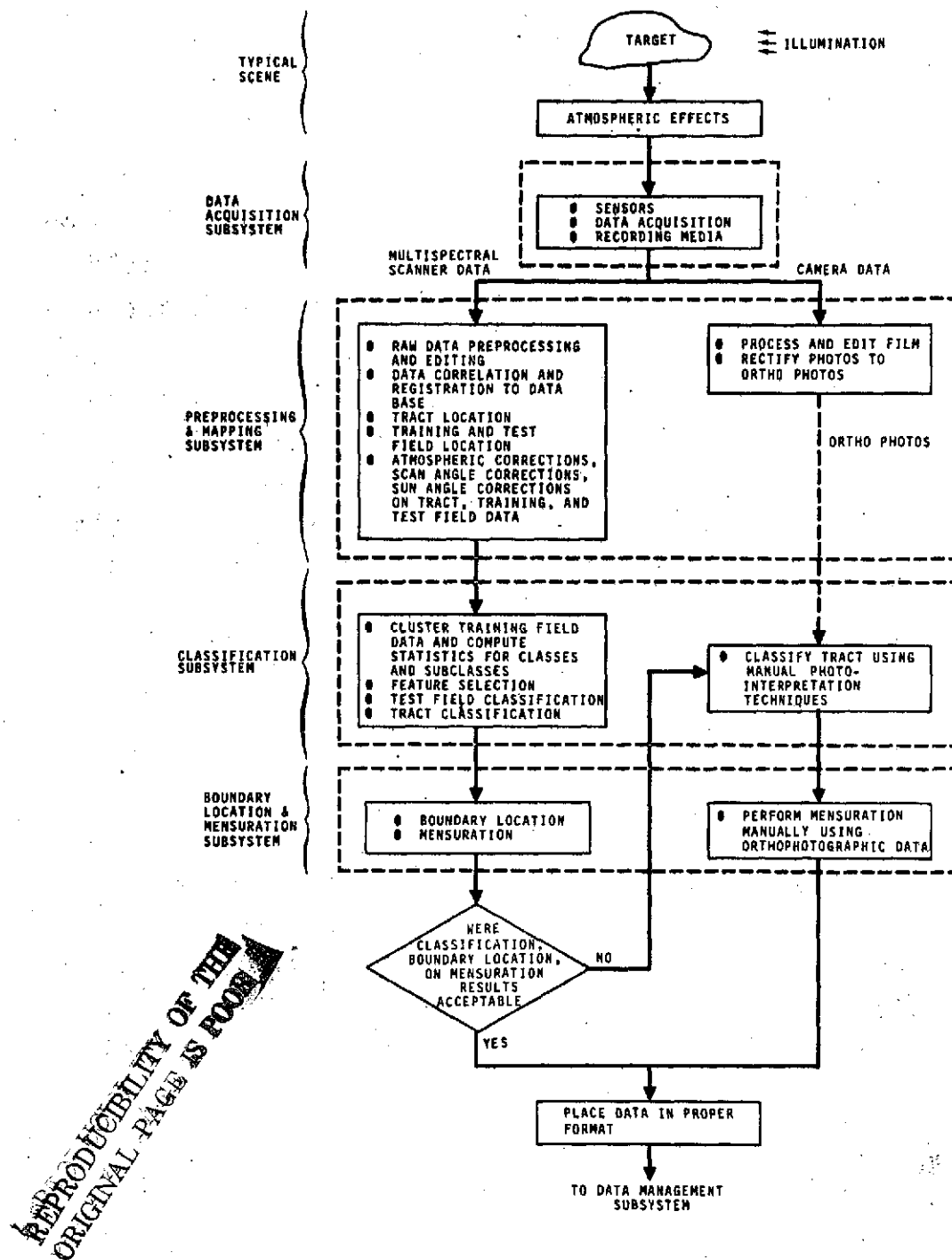


Figure 2.12 — A detailed breakdown on the elements of the data processing system.

base to remove distortions from the scanner data and to locate the scanner data on the reference image. Construction of the reference image will be discussed in greater detail in section 2.2.4. The reference image will be a low-distortion digital image of the Corn Belt. The location on the reference image of all tracts and training and test fields in the ASCS program are assumed to be known. Registration allows the location of tracts and training and test fields on the scanner data, since their location is known on the reference image. With good registration, i.e., to within perhaps $\pm 1/2$ pixel, successive multispectral samples may be collected on any point on the ground from successive flights. This would allow temporal pattern recognition to be performed on tracts. The reference image can be constructed from rectified photography. The orthophoto is then digitized on a film converter and assembled into a digital mosaic of the Corn Belt, with final edge-matching accomplished on a digital computer.

- The tracts to be verified for compliance, as well as the training and test fields, are located on the MSS data. Radiometric corrections are then applied to the tract, and to the training and test field data, through the correlation and registration process. This process corrects signature variability caused by conditions such as atmospheric differences and sun and scan angles.
- Training field data is then clustered to obtain unimodal classes and subclasses, and statistics are computed for each class or subclass. Each channel

is selected for its ability to perform temporal pattern recognition, and classification accuracies are verified using independent data from the test fields.

- Using temporal information, pattern classification is performed on tracts which are being checked for compliance with ASCS program requirements.
- Field boundaries are identified and field acreages are computed. Adjustments are made for turn rows and unproductive areas such as potholes and rock outcroppings.
- The computer results are reviewed to determine if the results of the classification, boundary location, and mensuration are acceptable. Any tract where results are questionable is flagged for further analysis by a photointerpreter. Fields which would qualify for further analysis include any field which (1) contains a crop for which adequate classification accuracies were not obtained on test fields, (2) has a large number of points classified into more than one class or the null class, (3) contains numerous boundaries, perhaps as a result of skip-row planting practices, or (4) has cloud shadow or tree shadow along a field boundary noted by a photointerpreter in the MSS photographic data. Many of these criteria will indicate doing further analysis on a tract.
- The results of the tract analysis are formatted and forwarded to the data management facility for storage and dissemination to county ASCS offices.

2.2.4 Data Processing System Parameters

For the data processing system to meet the User Information Requirements, a number of performance criteria must be met. These include

- Correlate and register MSS data to the data base so that linear errors in the registered data are much less than approximately 0.5 percent in 460 feet and much less than 0.05 percent in 4,600 feet. These requirements are necessary to allow measurement of a 5-acre square with an error of 2 percent or less, or a 500-acre square field with an error of 0.9 acre or less. Both 5-acre and 500-acre fields are worst-case field sizes. In addition, registration accuracies of approximately $\pm 1/2$ pixel element or less are required to allow MSS data from successive flights to be used in temporal pattern recognition.
- Classify crops and land uses with an accuracy of 98 percent or better. Classification accuracies on independent test fields, which will be used to establish classification accuracies, are normally not as high as the accuracy obtained on training-field data due to problems in obtaining representative training samples. This implies that the feature selection technique will be required to select features (channels) so that the probability of correct classification on the training field data is much better than 98 percent. Features (channels) are normally selected using training-field data.
- Locate the boundaries of a field with an accuracy of ± 2 feet. This boundary location accuracy is required to allow measurement of a 5-acre field with an aspect

ratio of 1:5 or less, with an error less than 0.1 acre or 2 percent; a 45-acre field with an aspect ratio of approximately 1:50 or less, with an error less than 2 percent or 0.9 acre; or a 500-acre field with an aspect ratio of 1:5 or less, with an error of 0.9 acre. Fields 500 acres or larger in size with aspect ratios greater than approximately 1:5 are assumed to be handled by manual techniques.

In the following sections, the feasibility of developing the proposed system and how these system parameters will be met are considered.

2.2.5 Data Correlation and Registration

In this section data correlation and registration will be discussed.

Image correlation is the process by which the point-by-point relationships between the elements of two images can be established. Image registration is the mathematical technique which uses the results of image correlation to bring into spatial agreement the overlay image and the reference image.

In the framework of the ASCS proposal, an automated image correlation/registration scheme is a mathematical operation on the imagery data using a digital computer to accomplish at least the following tasks:

- Register data gathered from different sensor platforms to a groundbased system with specified accuracy.

- Register one image to another, e.g., temporal registration. Register data taken from different sensor platforms at different times and in different environments.
- Create digital mosaics from small but overlapping imagery.

The objectives of data correlation and registration for ASCS applications involve at least the following:

- Perform spectral and/or temporal pattern recognition using data from different sensors in different environments.
- Perform short-term change detection and agriculture field history recording.
- Simplify data management. Remote sensor MSS data is characterized not only by its spectral and temporal information contents, but also by its spatial location in some convenient coordinate system. When data correlation/registration is performed relative to a well-established base map, the spatial portion of the information can be deleted, thereby simplifying the data storage and retrieval tasks. When data correlation/registration is used together with available boundary information on certain agriculture fields, data management is further simplified, since information can then be stored not on a "per-point" but on a "per-field" basis.

2.2.5.1 Registration problems.— The following discussion deals with some of the basic difficulties that can be expected in trying to accurately correlate and register images for ASCS applications:

- Registration accuracy versus sensor characteristics: Wakeman and Hart [2] were able to establish some bounds on the minimum error attainable in location accuracy based on the assumed performance characteristics of the existing sensors and platforms for remote sensing applications. Unless the inherent sensor capabilities exceed certain established thresholds, the discussion of accurately registering image data from these sensors will lose its meaning.
- Registration accuracy versus data volume: It is natural to expect that the more accuracy desired, the more digital data processing steps involved. There is a tradeoff on the accuracy when considering that given certain computer processing capabilities, most if not all remote sensing ASCS data needs to be correlated and registered before the information content can be meaningfully extracted. In order to be able to deal with the huge volumes of data involved, some registration accuracy may have to be sacrificed.
- Registration accuracy versus the quantized nature of data: As stated in the introduction of this report, all data to be processed is assumed to be in digital format. Two-dimensional continuous images are represented by a data matrix, with each entry of the matrix a function of the resolution-cell size of the sensor, the atmosphere through which the sensor looks, and the recording-reformatting system characteristics

that produce the quantized data. It is difficult to associate a data value so generated with a specific point on the ground. The difficulties are compounded when different sensors with different resolution-cell sizes are flown at different altitudes at different times and then are registered together. The errors due to uncertainty of location, radiometric differences, and digital quantized noise, usually cannot be minimized altogether.

It is clear that when one asks how accurately the data is registered, the accuracy must be discussed in light of the above three contradictory effects.

2.2.5.2 Existing data correlation/registration systems.—

Most of the existing automated data correlation/registration systems base their algorithms on the following approaches:

- Image correlation: A set of "matching points" are picked on both the reference and the overlay images by one of the three methods discussed below. The basic condition necessary here is that both the reference and the overlay images have about the same resolution-cell sizes. Finding matching points between two images with different resolution-cell sizes involves multistage sampling or other special techniques, and to the author's knowledge none of these techniques are widely accepted at present.
 1. Display the two images and manually pick the matching points.
 2. Slide a small "patch" of the overlay image over the reference image and compute the correlation

coefficient or its equivalent until a maximum or minimum peak is found. Then, in some orderly fashion, take another "patch" of data from the overlay image and compute another correlation peak. Continue the process until the whole image is covered by a correlation grid structure. To compute the correlation coefficients, either a direct numerical evaluation, a Fast Fourier Transform (FFT) [3], or some other more specialized scheme can be employed. The spacings between the grids are determined by the amount of distortion existing between the two images.

3. Use a combination of the manual and automated approaches discussed above. This method can be employed when a set of ground control points is available for correlation. Optical correlation techniques also can be used toward these ends if the data format of the ground control points and the image data available are suitable for optical processing.
- Image registration: Based on the information obtained from image correlation, image registration can be accomplished by a variety of local or global rubber-sheet fitting techniques. These techniques are derived from goodness criteria and employ a variety of constraints. All differential scaling, rotational, and translation errors indicated by the correlation results can thus be corrected. For example, global bivariate polynomial approximating functions, using the least-square criterion with no constraint, can be applied to the overlay image to bring it into

registration with the reference image. During the registration process, more than one overlay image can be used, and a point shift algorithm [4] can be used to save processing time.

The following is a discussion of the highlights of some of the digital image correlation/registration systems now in existence:

- The CDC system [5]: The Control Data Corporation system is one of the more sophisticated systems in existence, with extended capabilities in digital imagery processing starting from raw film scan. It uses direct numerical methods for data correlation, applies bivariate polynomials up to the fifth order, and uses the least-square criterion to compute the coefficients of the approximating functions for registration. It also corrects the radiometric error and can register images in the continuous-film format. The CDC system is currently used by MSC for ERTS data processing.
- The LARS/Purdue system [6]: This system is one of the earliest in existence. It requires minimum man-machine interaction and is designed mainly for registering data from long but narrow flight lines. It uses the FFT technique to generate correlation grid structure and applies a linear spline-fit procedure for data registration. A maximum of three overlay images can be registered to the reference image at the same time.
- The IBM system [7]: This system is currently used at Goddard Space Flight Center for processing the

ERTS, MSS, and RBV data. It uses the sequential similarity detection algorithm (SSDA) for determining image correlation, and the bivariate polynomial approximation with the least-square criterion for doing registration. During the registration process, IBM's point-shift [4] algorithm is used to speed up processing. Registration accuracy for ERTS imagery is claimed to be within one pixel element.

- The LEC system [8]: The Lockheed Electronics Company system evolved from the LARS/Purdue and IBM systems will possess the advantages of both when put into operation in the near future. It uses either the FFT or the SSDA method for performing image correlation. For registration, it employs a localized, adaptive, lower-order, bivariate polynomial approximation for representation of localized distortions. In addition, the boundaries surrounding the localized regions are constrained to be continuous from one region to the other. This system is capable of correcting all types of image distortions that may be present in the overlay imagery.
- The University of Kansas system: This system deals mainly with digitized radar imagery. Its data correlation/registration capability is limited.

2.2.5.3 Conclusion and recommendations.— The various techniques for digital imagery correlation/registration discussed above are far from being perfected. One of the major limitations is that even on a large-scale digital computer system designed for image data processing, such as the one

used in the CDC system, the amount of time involved in computing the correlation between two medium-sized images (e.g., 4096 by 4096 pixels) is excessive [5]. In fact, compared to correlation, the amount of computer time used by the registration processor is usually a small fraction of the total time. SSDA is claimed to be an order of magnitude faster than the FFT or the direct numerical correlation computation, but it involves the additional adjustment of a threshold parameter which adds one more degree of freedom to the already complicated system. Note that the spatial as well as the texture information in the reference and the overlay images are hardly used. Digital processing, though versatile, is too slow for the amount of data involved in ASCS applications. Future research efforts in image data correlation/registration should be directed toward the following two areas:

- Investigate optical-mechanical techniques to supplement digital techniques for image correlation. Optical-mechanical data processing may not have the versatility and the accuracy of a complete digital processing system, but it excels in processing speed.
- Investigate the use of a parallel digital processing system similar to the ILLIAC IV system [9]. This system can speed up the correlation process considerably, but it may require incorporation of spatial and texture information in image correlation computation.

2.2.6 Training Field Selection, Feature Selection, and Pattern Classifiers

When one considers the state-of-the-art in remote sensing today, a quality of system types becomes readily apparent. This quality is attributable to two somewhat different types of technology, which will be referred to here as

- Photoimagery analysis
- Automated pattern recognition

A photoimagery analysis system consists of an aerial camera and a photointerpreter. Typical output is the determination of specific classes of surface cover from observable spectral/spatial variations detected in the photographic film. Automated pattern recognition, however, uses computers for data analysis. It is not the purpose in this section to discuss the two systems as separate entities, but to point out the potential offered by the two working together to define the state-of-the-art, specifically in the area of pattern classification.

2.2.6.1 Training field selection.— One limitation to the success of identifying crop species is the variability of crop type and land use. One way of removing variability is to preprocess the data, adjusting for variables which may result in misclassification. However, the most important procedure for successful classification is selecting training samples which are representative of the categories to be distinguished.

Currently, ground truth is often taken very carelessly. The information that is usually taken is (1) the crop category growing in each field, (2) its stage of maturity and condition, (3) the percentage of ground covered by vegetation and crop height, (4) the direction of ground covered by vegetation and crop height, and (5) the direction of rows (if any). In the future, training field selection will require soil moisture, presence and extent of invading species and weeds, the percent of bare areas in fields, vigor descriptions where applicable, and detailed mapping of the field environment (i.e., tractor accesses, storage pens, and drainage and irrigation lines). Current specifications do not provide the needed information to meet these requirements.

Under the present classification system, using the Gaussian maximum likelihood classifier, training fields for each class are assumed to be Gaussian and the classifier assumes it is classifying unimodal data. The Gaussian assumption is justified by the many phenomena encountered in nature having Gaussian distributions. However, individual training sets for a given class usually determine a multimodal situation; consequently, a unimodal classifier is forced to classify multimodal data. Since the ASCS will provide preselected ground truth fields for candidate training field selection sites, the following should be implemented to adjust the data to the underlying assumption. Training fields for a given class should be available throughout the flight line and should be put together and clustered [10] using a mode-seeking cluster routine, such as the routine ISODATA of Ball and Hall [11]. It is expected that even a crude cluster routine would result in improvement.

The greater the ability of the cluster routine to yield unimodal subclasses, the better the performance of the classifier should be. The present capabilities of ISODATA are lacking as far as ASCS objectives are concerned, but its use is worthwhile because it improves classification accuracy.

The separate clusters can be used as training samples for subclasses. This would result in training data that adheres more closely to the assumptions. Also, different training fields for the same class would be used throughout the flight line, and subclasses in the neighborhood of the aircraft would be prime candidates into which a pixel may be classified. Figure 2.13 shows how this procedure might be used to break corn training fields up into unimodal subclasses.

Multiband and multidata photography exhibiting the greatest differences in crop signatures will prove indispensable in discriminating one crop from another. In particular, spatial and temporal features can be recovered from this type of photography and will aid in training field selection. For example, the photointerpreter can aid in determining which times of the year are best for discriminating between crops. This will lead to a crop calendar which should change very little from year to year (fig. 2.14).

2.2.6.2 Feature selection.— Generally, two types of criteria functions exist for feature selection: (1) those which measure the separability of the transformed samples with respect to a particular decision rule, such as parametric techniques, and (2) those which measure the separability independent of the decision. The first approach is the most accurate in obtaining the best features for the decision rule

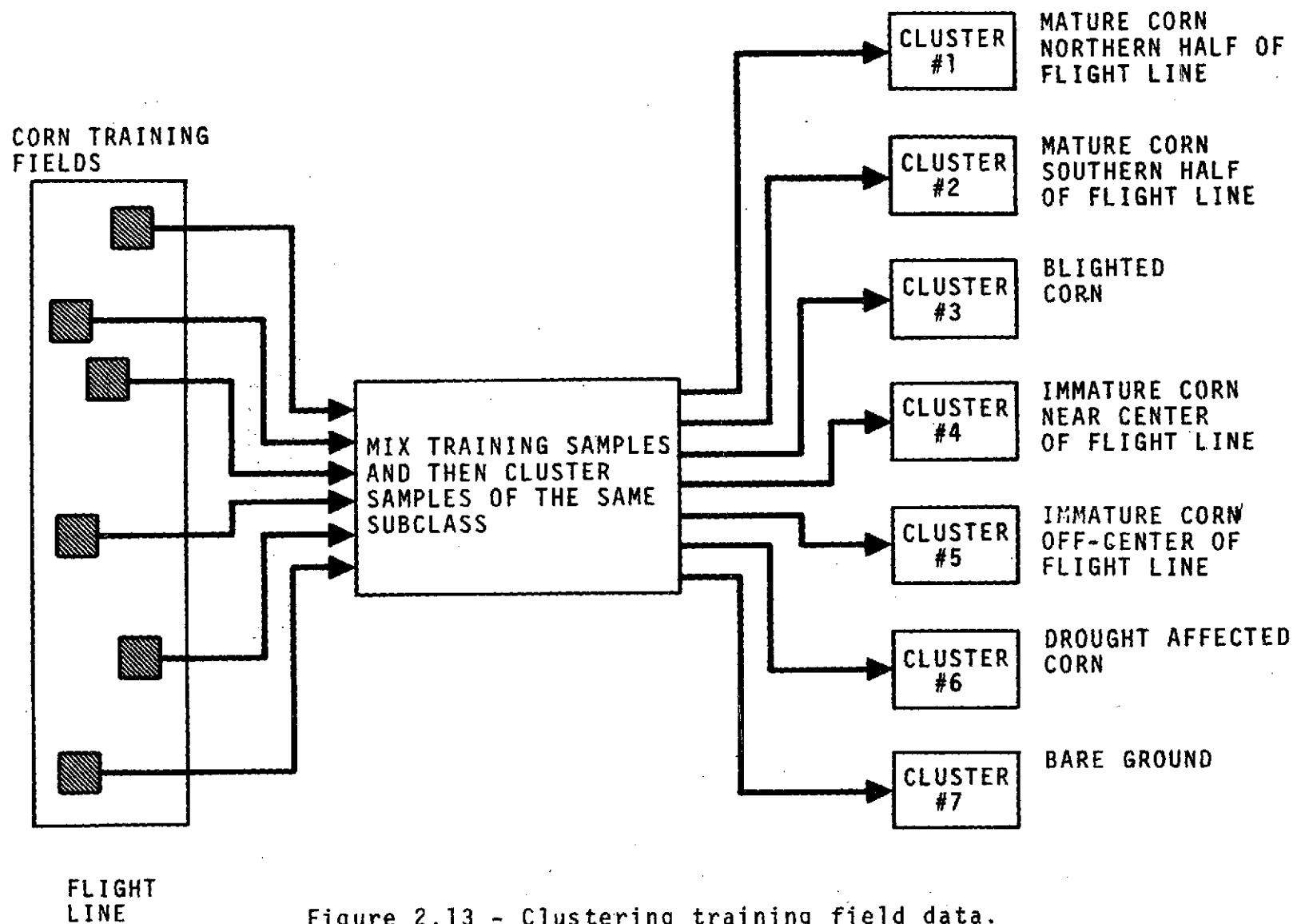
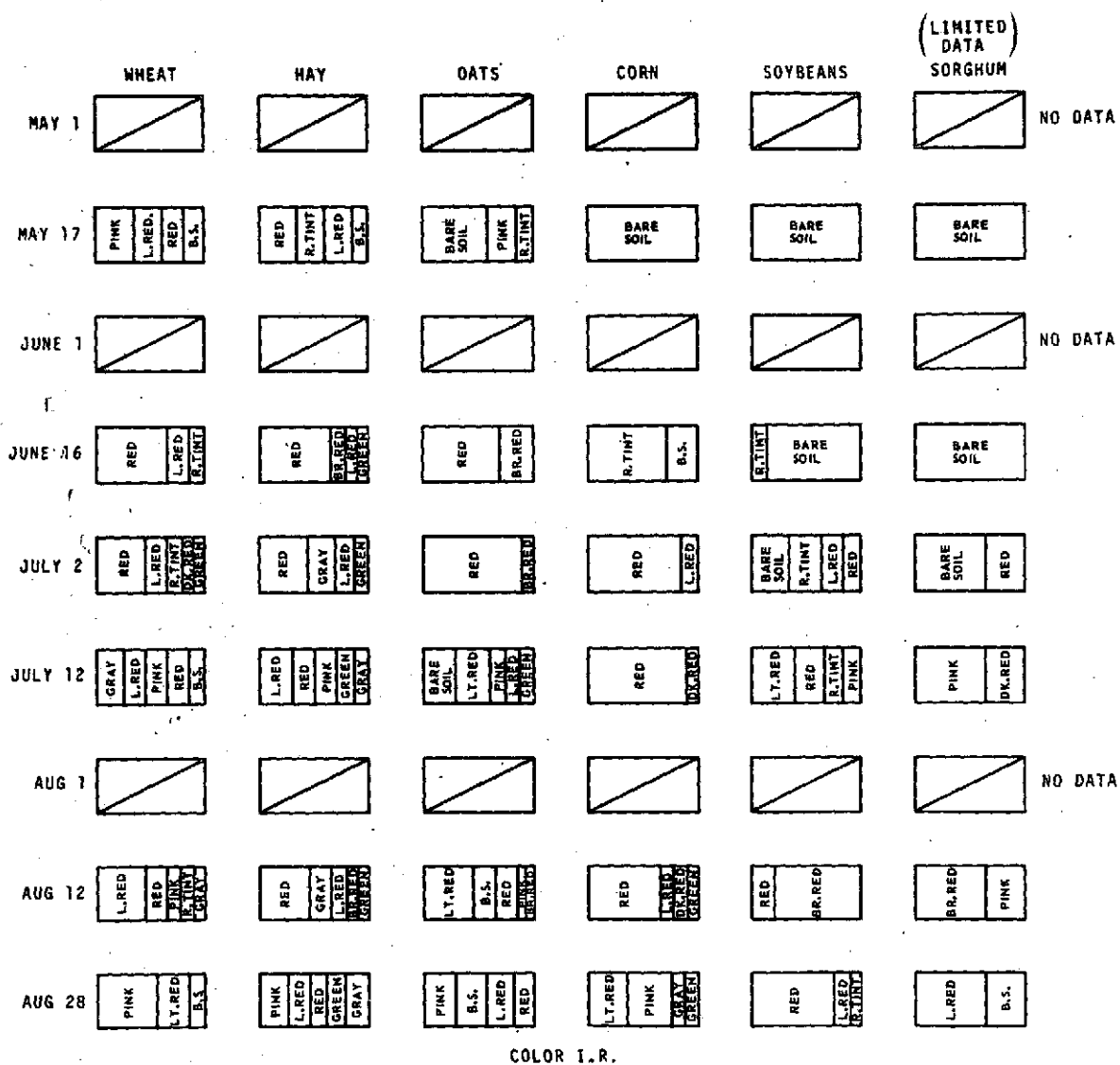


Figure 2.13 - Clustering training field data.



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Figure 2.14 — Seasonal response calendar.

to be used, but it is usually computationally costly. The second approach obtains the best features for which the class probabilities overlay the least and requires less computation.

At present there are no unique feature selection techniques for all the possible pattern recognition problems. However, since for the ASCS project class distributions can be approximated by Gaussian distributions, the probability of misclassification gives some evaluation of feature effectiveness. Many techniques exist which are related in an indeterminable way to the probability of misclassification. Some existing approaches are the eigenvalue/eigenvector techniques (including factor analysis and principal components), standard regression techniques, Wilk's scatter technique, the divergence criterion, Sammon's nonlinear mapping, Wee's feature selection technique, and many others. Currently, many of the techniques are at the testing stage, and very few have been sufficiently compared over a multitude of situations.

The divergence criterion [12] is the most commonly used feature selection routine, and, until a procedure for efficient multiple integration is implemented, it is the state-of-the-art.

The limitation of the divergence criterion in feature selection can be offset by the photointerpreter. Feature selection via the divergence criterion is limited to multispectral features, and in many cases, such as at certain times of seasonal growth, it is difficult to discriminate between certain crops. Since the photointerpreter is usually successful in extracting temporal, textural, and spatial

features to delineate between crop species, it is able to construct a crop calendar which will aid in determining what time and location would be best in distinguishing between crop species. For example, rather than trying to distinguish corn from soybeans at a time and flight when these are difficult to distinguish, classification may have to be restricted to an earlier or later time and flight.

In the immediate future, the research phase of feature selection should be oriented toward the probability of misclassification, since the divergence criterion is an arbitrary and insufficient method for achieving the prototype status required by the ASCS. Figure 2.15 shows the relationship between divergence and the probability of correct classification [12]. The graph shows that for a probability of correct classification of 98 percent or better, the divergence can have any value between 17 and infinity. For this range of divergence, though, the probability of correct classification may be as low as 84 percent. Correct classification of 98 percent or better is assured only for divergence values of 1,000 or greater. Considering feature subsets which have divergences greater than 1000 would severely limit feature selection, if none of the feature subsets considered had a divergence greater than 1000. However, if one of the feature subsets has a divergence between 17 and 1000, it could possibly provide the 98 percent correct classification required.

Work is being done on this problem, and the outlook is optimistic for a good feature selection criterion [13]. For the accuracy demanded by the ASCS project over such a variety of crop species, it is expected that the choice of

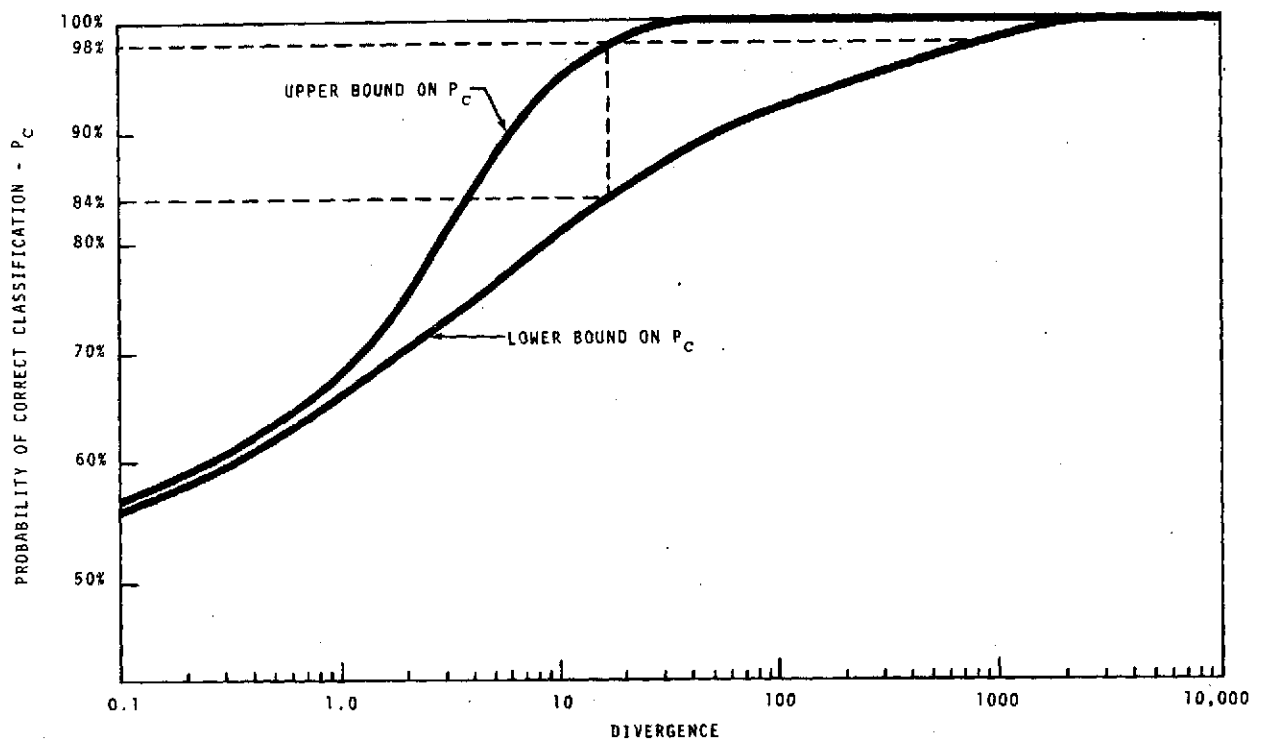


Figure 2.15 - Relationship between divergence and the probability of correct classification.

a set of features for all the classes together will not suffice for efficient discrimination purposes. Instead, it may become necessary to select pairwise discriminatory features. For example, the features used to discriminate alfalfa from barley will undoubtedly be different from the features that best discriminate between alfalfa and bare soil, corn, or wheat. If this is the case, it is recommended that such a system be implemented into the prototype system.

Feature selection is really a two-part problem. The feature subset evaluation criterion just discussed is one problem, and the feature subset search procedure is the other problem.

To pick the best n features out of L features (i.e., the best six channels out of 12 channels of scanner data) on the MSC version of LARSYS, the number of feature subsets of size n which have to be considered is

$$\binom{L}{n} = \frac{L!}{(L-n)!n!} \quad (2.1)$$

This exhaustive search procedure is an optimal procedure.

For each of the feature subsets considered, the divergence is computed between all pairwise combinations of the M classes involved. The number of pairwise combinations of divergence to be computed is:

$$\binom{M}{2} = \frac{M!}{2(M-2)!} \quad (2.2)$$

Therefore, to select the best n features out of L features for M classes, the divergence has to be evaluated combining equations (2.1) and (2.2)

$$NP = \frac{M!}{2(M-2)!} \cdot \frac{L!}{(L-n)!n!} \quad (2.3)$$

where NP is the number of times a pairwise divergence is computed.

This means that if a 10-channel system is flown over the Corn Belt at four different times in a crop growing season and it is desired to do temporal pattern recognition using all 40 channels of the data collected, then to select the best 20 out of 40 channels (a worst-case condition) to classify seven classes of material, the number of pairwise divergences computed is (using equation 2.3):

$$NP = 2.9 \times 10^{12} \text{ pairwise divergence computations}$$

Assuming that a single calculation of the divergence between two classes takes approximately 53 milliseconds in a 20-dimension feature space [14], the amount of time required for a general-purpose digital computer to select the best 20 out of 40 channels would be approximately 43 million hours, which is obviously unacceptable. The only alternative is a more judicious procedure for selecting candidate feature subsets for evaluation. A number of suboptimal feature subset selection search procedures are available. These include the dynamic programming search procedure [15] and the without-replacement procedure [14].

Figure 2.16 shows some computation times for four different search procedures [14] using the divergence criteria for feature subset evaluation. Various numbers of channels were selected out of 12 channels with seven classes of material. Figure 2.17 shows a comparison of channels selected and classification accuracies of the various search procedures in figure 2.8 [14]. The without-replacement procedure is estimated to be able to select the best 20 out of 40 channels, using the divergence criterion for seven classes of material, in approximately 11.3 minutes of computer time. Computer times were not readily calculatable for the dynamic programming procedures for selecting the best 20 out of 40 channels. The dynamic programming procedure is a prime candidate for replacement of the exhaustive search procedure.

It is recommended that all of these suboptimal search procedures be further investigated to determine if they can be used to meet ASCS requirements.

2.2.6.3 Pattern classifiers.— The photoimagery system is a well-developed area and relatively inexpensive to use for classification purposes. However, for such a large-scale survey over the area required by the ASCS project, it is unfeasible; an automatic pattern classifier is needed. This is not to say that photoimagery analysis is to be eliminated in classification processing. On the contrary, it may prove to be indispensable in the selection of training fields and on many other occasions. In particular, areas whose classification using the automated procedure is highly questionable should be photographically reexamined by a photointerpreter for possible reclassification. The use of photointerpretation as a backup to automatic pattern classification will be discussed further in section 2.2.10.

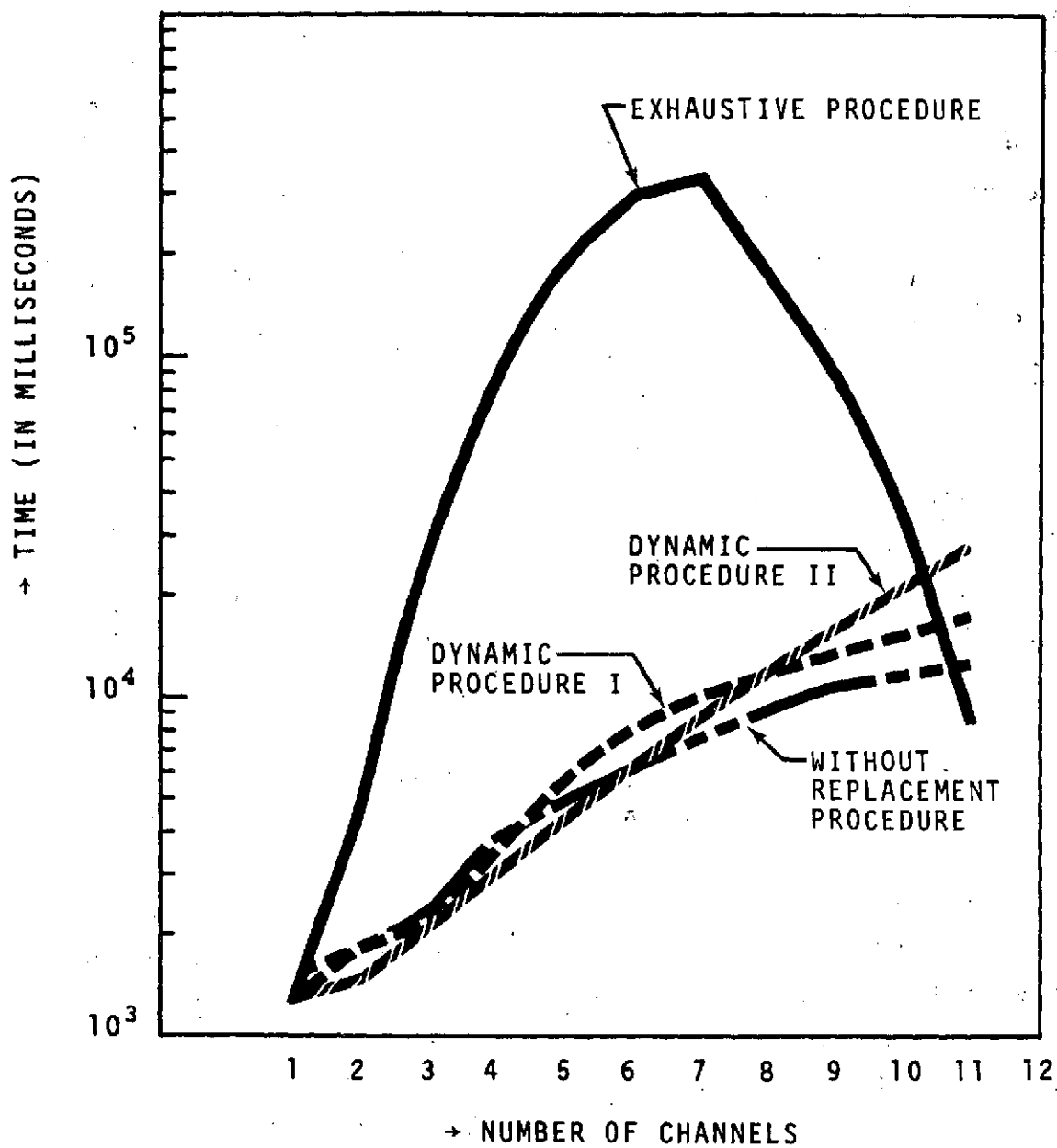


Figure 2.16 — Feature selection timing chart.

CLASSIFICATION
AVERAGE PERFORMANCE BY CLASS

<u>WITHOUT-REPLACEMENT METHOD</u>		<u>DYNAMIC PROCEDURE I</u>	
<u>CHANNELS</u>	<u>% ACCURACY</u>	<u>CHANNELS</u>	<u>% ACCURACY</u>
12	38.2	12	38.2
9,12	63.1	9,12	63.1
6,9,12	77.3	6,9,12	77.3
6,9,10,12	79.5	6,9,10,12	79.5
1,6,9,10,12	85.6	1,6,9,10,12	85.6
1,6,9,10,11,12	86.0	1,6,9,10,11,12	86.0
1,6,8,9,10,11,12	85.7	1,6,8,9,10,11,12	85.7
1,2,6,8,9,10,11,12	86.2	1,2,6,8,9,10,11,12	86.2
1,2,6,7,8,9,10,11,12	85.7	1,2,6,7,8,9,10,11,12	85.7
1,2,5,6,7,8,9,10,11,12	85.6	1,2,5,6,7,8,9,10,11,12	85.6
1,2,4,5,6,7,8,9,10,11,12	85.9	1,2,4,5,6,7,8,9,10,11,12	85.9

<u>DYNAMIC PROCEDURE II</u>		<u>EXHAUSTIVE PROCEDURE</u>	
<u>CHANNELS</u>	<u>% ACCURACY</u>	<u>CHANNELS</u>	<u>% ACCURACY</u>
12	38.2	12	38.2
9,12	63.1	9,12	63.1
6,9,12	77.3	6,10,12	77.2
6,10,11,12	77.8	6,10,11,12	77.8
1,6,9,10,12	85.6	1,6,8,10,12	84.4
1,6,8,10,11,12	84.7	1,6,8,10,11,12	84.7
1,6,8,9,10,11,12	85.7	1,6,8,9,10,11,12	85.7
1,2,6,8,9,10,11,12	86.2	1,2,6,8,9,10,11,12	86.2
1,2,6,7,8,9,10,11,12	85.7	1,2,6,7,8,9,10,11,12	85.7
1,2,5,6,7,8,9,10,11,12	85.6	1,2,5,6,7,8,9,10,11,12	85.6
1,2,4,5,6,7,8,9,10,11,12	85.9	1,2,4,5,6,7,8,9,10,11,12	85.9

Figure 2.17.— Average performance by class.

The technology for automatic pattern recognition is much newer and not nearly so well developed, though very rapid progress is being made. Pertinent to the operation of an automatic pattern recognition system is the need for a pattern classifier. The mere number of pattern classifiers in the literature is indicative of the intensity and volume of research that is being devoted to automated procedures. In particular, there is the Bayes classifier, the nearest neighbor rule, the linear discriminant, the nonlinear discriminant, nonparametric classifiers, per-field classifiers (as opposed to per-point), Wald's sequential likelihood classifier, and K-class I. Measures, means, methods, and facilities for evaluating and testing the effectiveness of existing classifiers are required if each can be quantitatively assessed. However, it is becoming obvious from a functional point of view that there is no best pattern classifier. There are a host of competing techniques from which one or some combination may be chosen, but not strictly on the basis of a clear operating superiority over its competitors. The quantitative efficiency and reliability of any given technique has not been established in general.

It is well known to workers in remote sensing, however, that encouraging results have been obtained in the classification of terrain types on the basis of statistical models derived from training sets, particularly in crop species identification. Considering both theory and results in the literature, preference for a per-point classifier has to be given to the Gaussian maximum likelihood classifier [16] as the state-of-the-art in classification processing of MSS crop type data. It is well known that the accuracy of this classifier is dependent upon the variability of crop type

and cropping practices. Consequently, when a large training sample truly representative of the expected operating condition is available, one cannot do better than to train or design the classifier to perform as well as possible on this training set.

Currently, a significant improvement in the capability of the maximum likelihood classifier awaits the development of an efficient preprocessing technique for signature extension purposes, an efficient clustering technique to aid in the selection of training fields, and an efficient feature selection criterion for optimal discriminating purposes or data reduction. Even though the Gaussian classifier has worked effectively for many cases without the use of such aids, these techniques will be necessary for the establishment of a prototype system to achieve ASCS objectives. Figure 2.18 shows some classification accuracies for ground cover types over a 500-square-mile area in the Corn Belt [10].

A strong contender to the Gaussian maximum likelihood classifier is the per-field classifier [17]. The divergence distance function between two categories has been consistently better than the per-point classifier. However, the large improvement in overall accuracy achieved with per-field classification must be viewed with suspicion until a completely automatic method of detecting field boundaries is developed.

The standard per-field classifier classifies the members inside a specific boundary by looking at a subset of those members, as opposed to the per-point classifier which must look at and classify each individual pixel. This is

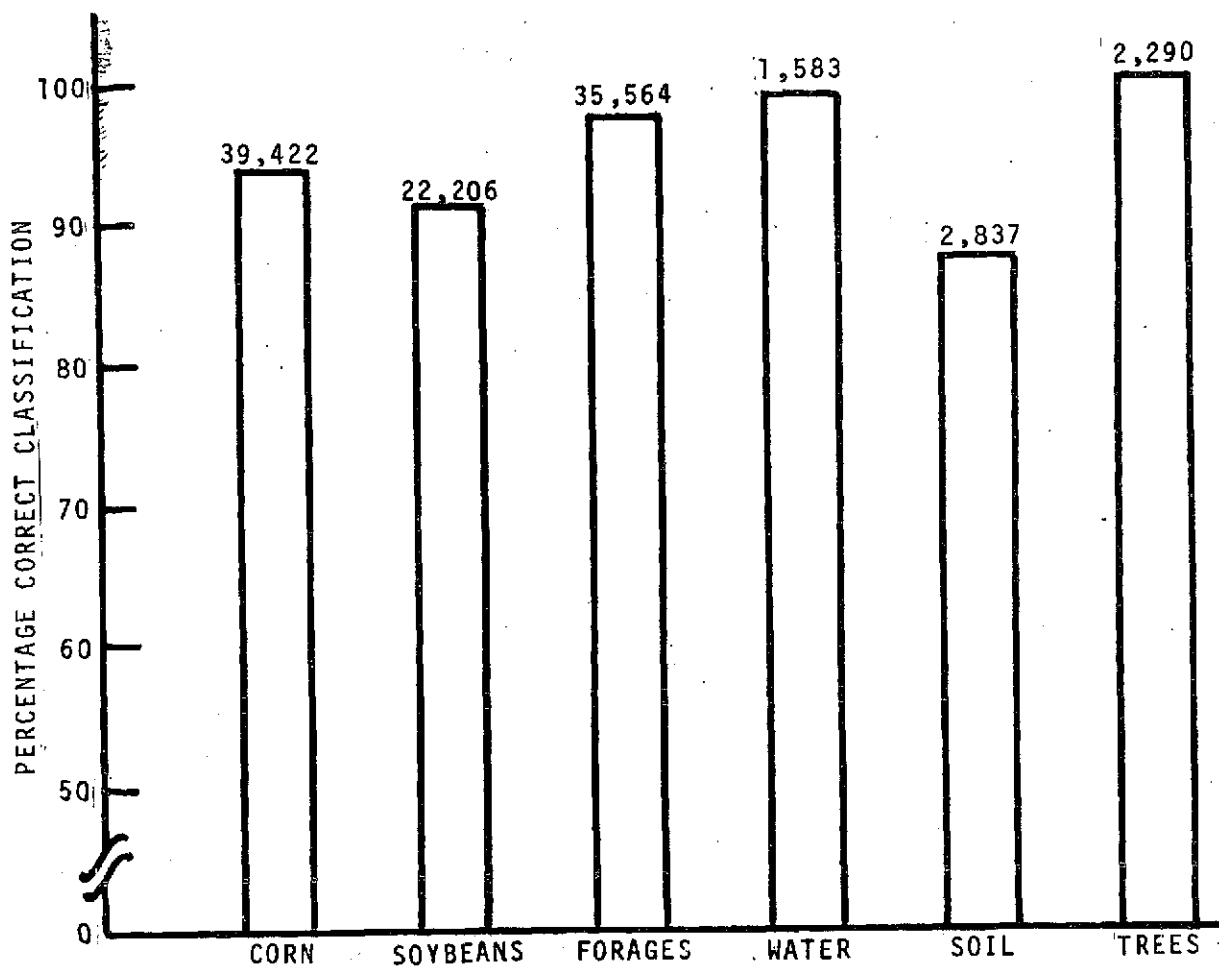


Figure 2.18 — Graph showing accuracy of cover-type classification using the maximum likelihood classifier for test samples representing a 500 square-mile area. (Numbers indicate total data points tested in each class.)

attractive statistically since the decision of crop species is based on not one element but essentially the average characteristics of several representative members. It would, in fact, be advisable to randomly pick the members used in the classification from within the boundary, since this would yield a representative sample of the elements in the field for the decision. Obviously, this would amount to a savings in processing time as well.

The relative computer time requirements and computations of the maximum likelihood classifier will depend on the type of processing unit available. If the system is analog, the classification can be done in real time (or faster) by using parallel processing capabilities. If one is restricted to a digital system, the Eppler table look-up algorithm has many desirable features and appears to be the state-of-the-art.

With either the maximum likelihood classifier or the per-field classifier, it is expected that use of temporal information should significantly improve their performance.

From spacecraft altitudes, limits on the refinement of ground resolution elements seen by a multispectral sensor sometimes significantly restrict the amount of useful information that can be extracted from the data using standard processing techniques. From those altitudes, many of the ground resolution elements are individually comprised of a mixture of object categories and many of the data points generated by multispectral sensors are not characteristic of any one object category. Consequently, the need is evident for a model for relating a combination of categories to the

individual categories which would permit a recovery of information. This is commonly referred to as the category mixtures problem.

The state-of-the-art is essentially void. The University of Michigan [18], TRW [19], and LEC [20] have each formulated a model from which the proportions of coverage by object categories can be obtained, however, these models are purely experimental. If data collected from spacecraft altitudes results in data from large resolution elements having to be processed, the category mixture problem will have to be seriously studied. This approach, though, does not appear to be feasible for the ASCS project.

2.2.7 Boundary Detection

The objectives in boundary finding [21] as far as ASCS is concerned include the following:

- Image registration: Enhanced boundaries help image registration, especially in the areas of temporal registration and registration of an image to a ground coordinate system. Most ground control points are located on a boundary or surrounded by it.
- Change detection: Detection of manmade and natural boundaries in agricultural fields is the prime objective of the ASCS proposal.
- Image classification: A boundary detection scheme is a necessary part of certain pattern recognition classifiers such as the per-field classifier [17].
- Data storage and retrieval: After field boundaries are established, data storage and retrieval problems can be simplified. This point was discussed in relation to image correlation and registration.

2.2.7.1 Boundary characteristics.— From a remote sensor point of view, a boundary is identified by a change in reflectance at the sensor input at some particular location on the image plane, within some or all spectral bands that the sensor is observing. For ASCS applications, the following characteristics of a boundary must be taken into consideration before any reasonable detection scheme can be incorporated.

- Boundaries may be distinct in some spectral bands but not others.

- Agricultural boundaries are usually detected by a fairly abrupt reflectance change as compared to gradual changes in other boundaries.
- Boundaries are usually local in their properties. Spatial information is required to determine whether a boundary is really a boundary of interest. For example, the boundaries formed by a single rock inside a large corn field should probably not be emphasized. A similar situation applies to skip-row planting where boundaries between rows of crops are not of interest. The intelligent use of spatial information in boundary detection is very important, but, unfortunately, little research has been done on the subject. The science of spatial pattern recognition is as yet in its infancy.
- The boundaries of an agricultural field are usually closed, and they may be detected as such.
- Some agricultural boundaries can be identified by using texture information, if it is available. The incorporation of texture information in addition to spectral and spatial information for boundary detection should be pursued in detail.

2.2.7.2 Existing boundary detection schemes.— An ideal automated boundary detection scheme tailored to ASCS requirements needs to be computationally efficient and use all available spectral and spatial and possibly textural information to detect both the closed and the open boundaries of interest. The following is a discussion of some existing automated boundary finding systems that come close to the ASCS specifications.

- The Purdue system [22]: This system uses a data clustering technique to identify dissimilarities in a group of data. The dissimilarity indicates the existence of a boundary. Most spectral and some spatial information can be incorporated into the scheme. However, the system as it exists today is computationally tedious, and the boundaries identified are usually not closed. Also, only a small amount of data can be handled at a time. A breakthrough in data clustering techniques would make this system more attractive.
- The IBM/Purdue system [23]: This system is an improved version of the Purdue system. It minimizes the computation time involved, and the boundaries detected are closed boundaries. However, the preliminary results of the performance of this system fall below expectation.
- General gradient or Laplacian technique: Usually information contained in only one spectral band is used by this technique, and only the gradient along the X-axis can be easily computed. As is well known, taking derivatives is a noisy process, and false boundaries may be generated. Nevertheless, this technique is computationally very simple.
- The use of texture information [24]: Boundary finding using mainly texture information has been used to find cloud patterns from weather satellites with some success. It remains to be shown whether this method is also applicable to an agricultural environment.

- Other methods: There exists a variety of digital techniques, not based on multispectral information, that detect and identify lines or other special geometrical shapes in two-dimensional digital imagery. They may all be worth investigating, but they will not be discussed in this report.

2.2.7.3 Conclusion and recommendations.— The existing boundary finding techniques mentioned above leave much to be desired. Concealed in the spatial and textural distributions of an image is a wealth of boundary information. The development of a practical automated boundary-finding technique using noisy, quantized digital multispectral data should be pursued on two fronts. When the application is local in scope (such as doing change detection over a relatively small area), only small amounts of data will be involved at one time, and a combination of spectral and spatial information should be used. Different adaptive interactive techniques, including the use of final classification results, can also be employed to refine the boundary, and, if necessary, different threshold criteria tested. When the application is more general in scope and a large amount of data is involved, some spectral information may be sacrificed in favor of the inclusion of as much spatial information as possible. The existing boundary-finding systems all leave much to be desired, and more research should be carried out on all fronts.

2.2.8 Mensuration

It was found that several types of errors may result from areal field and boundary measurements on remote sensor imagery. They include the following major types:

- Errors due to image distortions and terrain relief.
- Human errors in equipment operation and data inputs.
- Errors caused from improperly maintained mensuration equipment.
- Errors induced from measurements on a progressively smaller scale imagery (low resolutions).
- Differences in accuracy percentage figures due to the size of the area measured. ("Large" area measurements are generally more accurate than equivalent "small" area measurements.)
- Errors due to boundary identification and delineations.

The first three of these error types can usually be ignored because, once detected, remedies can be taken to correct the conditions resulting in erroneous values.

The last three error types listed present a more serious problem. Errors induced when measuring on a progressively smaller scale imagery have been determined for some individual farm fields by the ASCS Feasibility Study Committee. Table 2-I gives the results of some of these measurements and shows that the percentage of error increases with smaller scale views of the same fields.

TABLE 2-1.— H. DELL FOSTER DIGITAL RECORDER
MENSURATION EXERCISE

Field Identity	Measured Acres RC-8, 1:120,000	True Acres	Percent Accuracy And Number In Error		Measured Acres RC-8, 1:37,000	Percent Accuracy And Number In Error	
LL-1, 2, 3	73	80	91%	+7	80	100%	+0
F-5	12	14	86%	+2	14	100%	+0
J-1, 2	33	27	82%	-6	29	93%	+2
N-1, 2, 10	29	32	91%	+3	31	97%	-1
AAA-1, 2	80	77	96%	-3	76	99%	-1
AAA-5, 6	73	80	91%	+7	80	100%	+0
GG-3, 7	82	78	95%	-4	79	99%	+1
LLL-1	56	55	98%	-1	56	98%	+1
EEE-8, 9	63	60	95%	-3	60	100%	+0

The following are some error percentages also derived by the ASCS Feasibility Study Committee emphasizing the additional effect of the relative sizes of the areas to be measured. Note that for each scale category, the percentage of error is greater for the smaller fields.

Scale	Error for 5-Acre Field	Error for 20-Acre Field	Error for 40-Acre Field
1/10,000	2%	1%	0.6%
1/60 000	5%	3%	2%
1/120,000	13%	6%	4%

All of the above described measurements were made on nearly rectangular shaped fields with well-defined boundaries and good scene contrast.

This will not be the case for the usual range vegetation groups, however, because these groups generally exhibit lower scene contrasts and rather indistinct boundaries. Areal measurements of range features will be considerably less accurate than those obtained for the agricultural fields. This is due to the nonuniformity of plant specie compositions within vegetation type areas, as well as variations in the immediately surrounding vegetation communities and terrain.

2.2.9 Computer Systems and Data Storage Requirements

To fully assess the feasibility of the ASCS project, data volumes and data processing loads need to be considered [25]. As a general requirement in the ASCS proposal,

it was specified that 90 percent of the compliance determinations would have to be completed by July 1 of each year. Also, data is to be collected in four surveys over a 300,000 square-mile area, but only 25 percent of it (75,000 square miles) would be processed. The amount of computer processing time required for this amount of area depends primarily on the size of the resolution element. Since the resolution element size has not been established, efforts were made to bracket the probable resolution element size and estimate data volumes and processing times. Resolution element sizes of 2 by 2 feet, 5 by 5 feet, 10 by 10 feet, and 20 by 20 feet were considered.

2.2.9.1 Computer processing times and storage requirements.— To estimate the computer processing loads, the number of computer processing steps for each resolution element from a 10-channel scanner was estimated first. Three computer configurations were then chosen for the estimation of computer processing times. The configurations chosen were a general purpose digital computer, a parallel digital computer, and a hybrid computer (such as an analog computer with a general purpose digital computer for control). Resolution element processing rates were estimated for these three configurations, as well as the time required for processing 25 percent of the data from four surveys of 300,000 square miles for various resolution element sizes. Data storage requirements were also estimated.

For a 10-channel scanner, the total number of processing steps was estimated to be approximately:

<u>Process</u>	<u>Step</u>
Registration	2,000
Sensor correction	2,500
Atmospheric correction	
Scan angle correction	
Sun angle correction	
Classification (10 classes)	2,000
Boundary location	1,000
Mensuration	500
Computer overhead	<u>3,000</u>
TOTAL	11,000

Effective execution rates of 1.3×10^6 instructions per second for a general purpose computer, and 2×10^8 instructions per second for a parallel digital computer [19] were assumed. The hybrid was assumed to process all steps in parallel with all 11,000 steps processed in $1/50,000$ of a second [26] and [27]. Based on these considerations, resolution element processing rates for the three computer configurations were estimated to be:

General purpose digital = 120 resolution elements/sec

Parallel digital = 18,000 resolution elements/sec

Hybrid computer = 50,000 resolution elements/sec

Figure 2.19 shows the total number of resolution elements of various sizes in a 300,000 square-mile area. Assuming that 25 percent of the resolution elements collected from four coverages of the Corn Belt are to be processed, the CPU times (in terms of 24-hour days) are shown in figure 2.20 for various resolution element sizes. The CPU times do not take into consideration such factors as setup times and computing training field statistics feature selection. The CPU time associated with the 10-by-10-foot resolution element is emphasized, since this appears to be a likely candidate for a resolution element size.

Figure 2.21 shows the total number of tapes or mass storage units required to store a single overflight of the Corn Belt (300,000 square miles with 30 percent sidelap on flight lines). A 10-channel multispectral scanner producing 8 bits of information per channel per resolution element was assumed to be used. The storage media was assumed to be either mass storage units (1 trillion bit capacity per unit), aircraft tapes (15 by 10^9 bits/tape), or ERTS type tapes (27 by 10^9 bits/tape).

2.2.9.2 Conclusions and recommendations.— As shown in figure 2.20, the general purpose digital computer appears to be impractical for processing the amount of data required by ASCS. For a 10-by-10-foot resolution element, it would take 7,500 days (24-hour days) to process 25 percent of four coverages of the Corn Belt. The parallel digital computer appears to be the most attractive alternative to a general purpose computer for meeting ASCS requirements and for development of a prototype system by 1976, with an operational system by the 1980's. For a 10-by-10-foot resolution

Resolution Element Size	2×2	5×5	10×10	20×20
Area				
300,000	19.3×10^{11}	3.1×10^{11}	7.7×10^{10}	1.92×10^{10}

Figure 2.19.— Total number of resolution elements in
300,000 square miles.

PROCESSING TIME FOR FOUR COVERAGES OF CORN BELT
(1/4 OF EACH 300,000 SQUARE MILE COVERAGE IS PROCESSED)

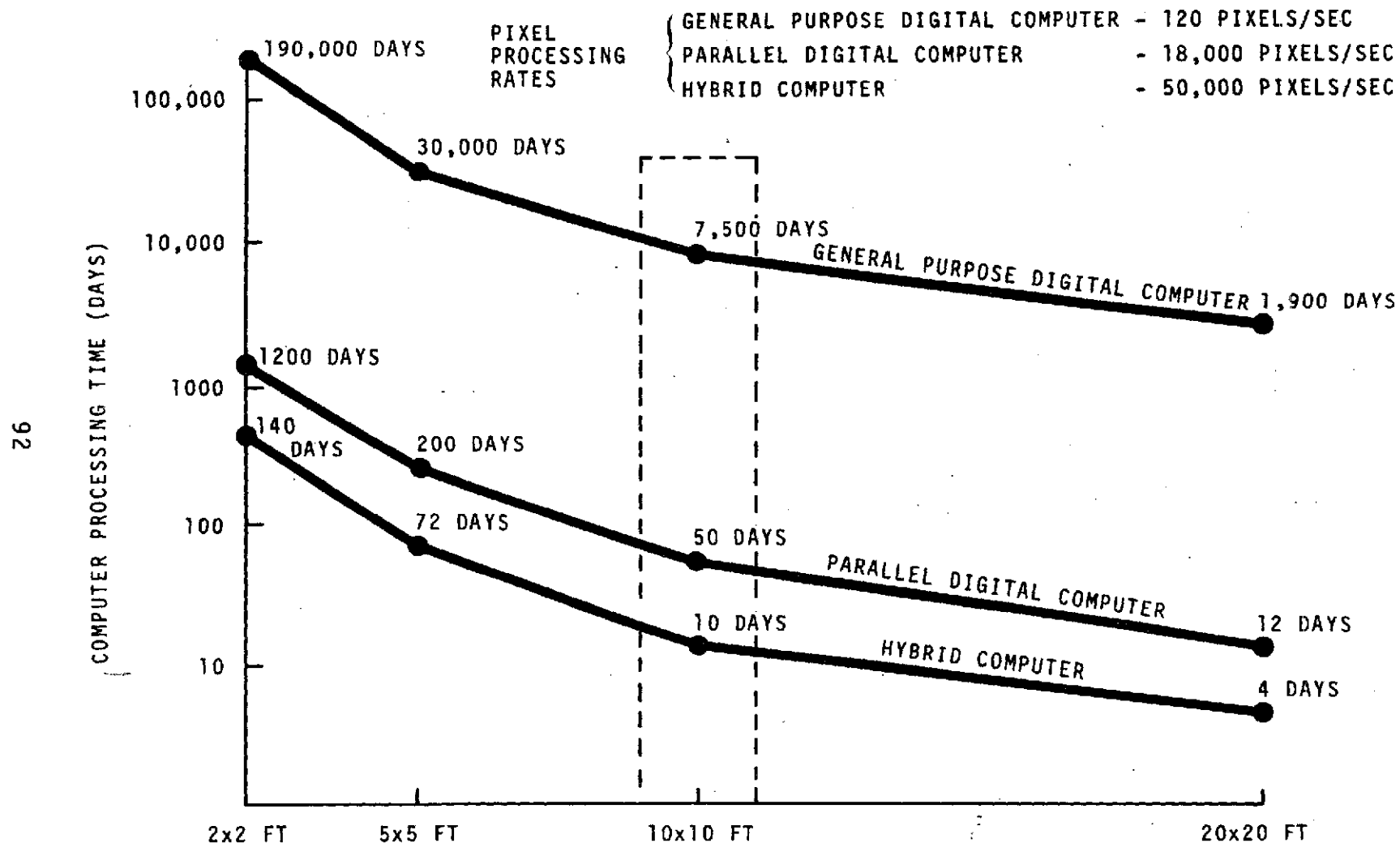


Figure 2.20 - CPU times for various resolution element sizes.

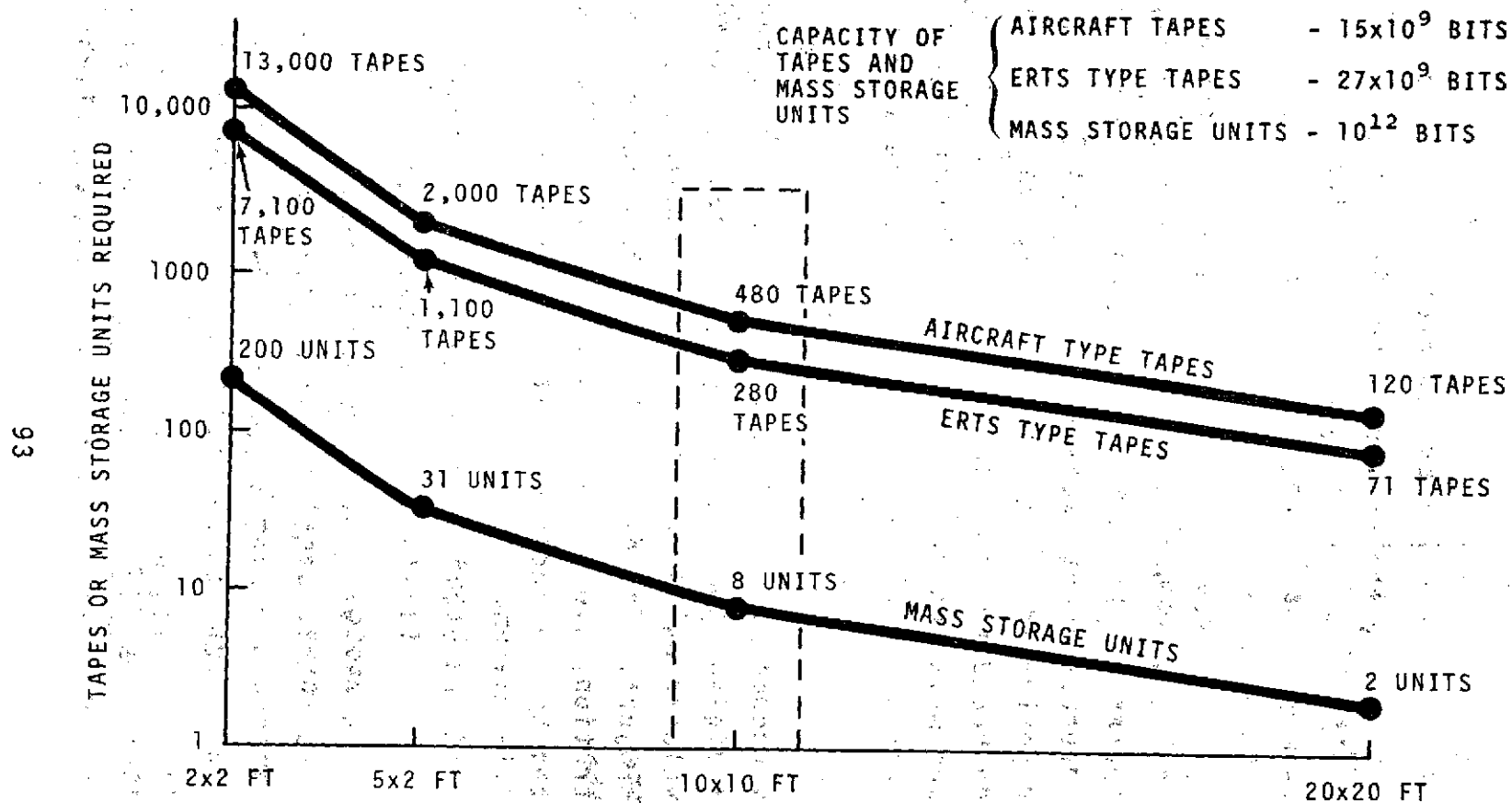


Figure 2.21 - Tapes or mass storage units required to store a single overflight of the Corn Belt. (300,000 miles with 30% sidelap in flight lines.)

element, it could take 50 days to process 25 percent of the data from four coverages of the Corn Belt. The hybrid computer is potentially the fastest and most economical method for processing the data, requiring 10 days to process the required Corn Belt data.

Currently, a major source of difficulty in the use of a hybrid computer is the lack of developed techniques for the hybrid to process remote sensor data. In particular, techniques for performing correlation and registration, clustering, and boundary location are not yet available for handling multispectral scanner data. This leaves in doubt whether a prototype hybrid system can be developed by 1976.

It is recommended that bench tests be conducted on both a parallel digital computer and a hybrid computer configuration to evaluate which of these systems should be used for the ASCS project. The difficulties in developing correlation and registration, clustering, and boundary location capabilities on the hybrid require additional evaluation.

2.2.10 Automatic, Semiautomatic, and Manual Classification Systems

Complex scene variables and the present state-of-the-art automatic remote sensing systems make it feasible for both automatic processing techniques and manual photointerpretation techniques to be used to classify fields.

2.2.10.1 Training field selection.— Crop classification by photoidentification of crop types along the flight line

aids in designating land for training fields and test fields. At present the following crop types can be identified temporally with a reasonably high degree of accuracy and repeatability.

Individually	{	Corn
		Soybeans
		Grain sorghum
Collectively	{	Small grains and grasses — winter wheat,
as one scene		hay, oats, pasture, nonrow crops

Semiautomatic mensuration devices are used to measure to the ASCS Administrative Variance the acreage of fields selected for training and test fields. Photoidentified crops and acreage measurements should be used by the ADP people to train and check the computer in temporal identification of crop types and to aid in the geometric correction of MSS data for automatic mensuration.

A rectified photo-product (orthophoto) should be produced with established geodetic control. This image will be digitized and the resulting data used to overlay with MSS data for geometric correction and registration. With this photo-product (analog), tract and field identification, visuals for reference and records, for updating ownership changes via ASCS records, and for delineating new subdivision boundaries will be prepared.

2.2.10.2 Manual field classification techniques.— The ASCS compliance program provides an excellent test for manual land-use classification techniques. The present Production Adjustment program (feed grains, wheat, and cotton) contains

the principal crops of interest in the proposed program. Crops in the Marketing Quota program (rice, peanuts, and tobacco) will not be included in the operational system program.

Major areas of land-use must be identifiable if remote sensing techniques are to be used in determining farmer compliance. Conventional photointerpretation techniques can and have been used to identify or verify crop types within an agricultural scene. The accuracy of these identifications can be determined where ground truth is available. For the purpose of this report, a crop identification experiment was initiated over a typical farm scene on a site within Montgomery County, Indiana. This test area was used for assessing the potential of aerial photography for temporal agricultural land-use classification (see figs. 2.22 and 2.23). Ektachrome-infrared images recorded from 60,000 feet with an RC-8 camera (6-inch focal length lens) during the 1971 growing season were used for the analysis. The approximate ground resolution of the RC-8 imagery is 15 feet.

Two image interpreters attempted to identify the crop types within the test area using seven images recorded between May and September. The interpretation team had access to field boundary information within the test area and was given training field examples for each crop type and for each temporal scene. By comparing the unknown fields against the training fields' signature responses, a month-by-month dichotomous elimination was attempted that would theoretically allow the interpreters to identify crop types.

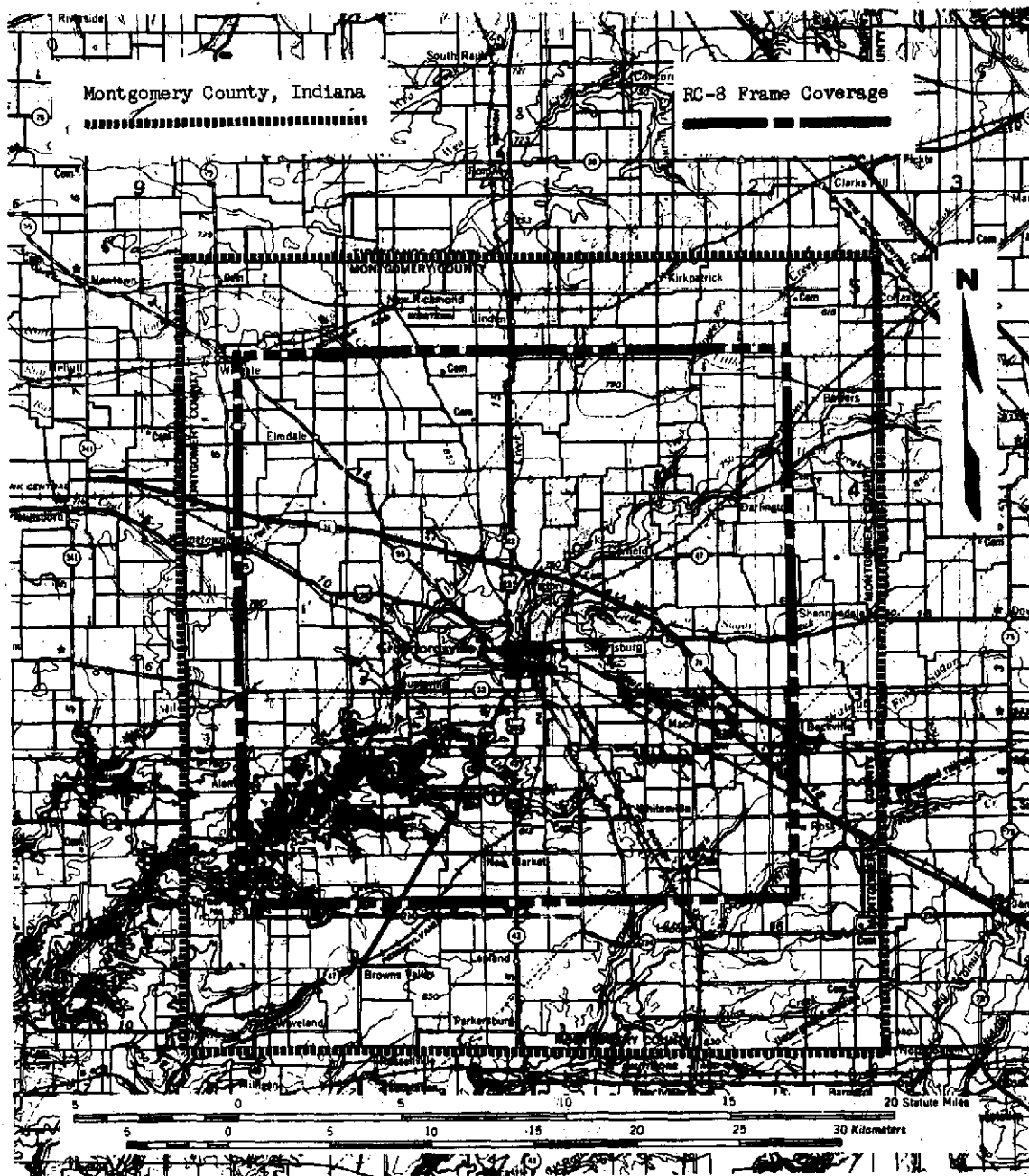


Figure 2.22 - Montgomery County, Indiana, and the coverage of one RC-8 camera frame.

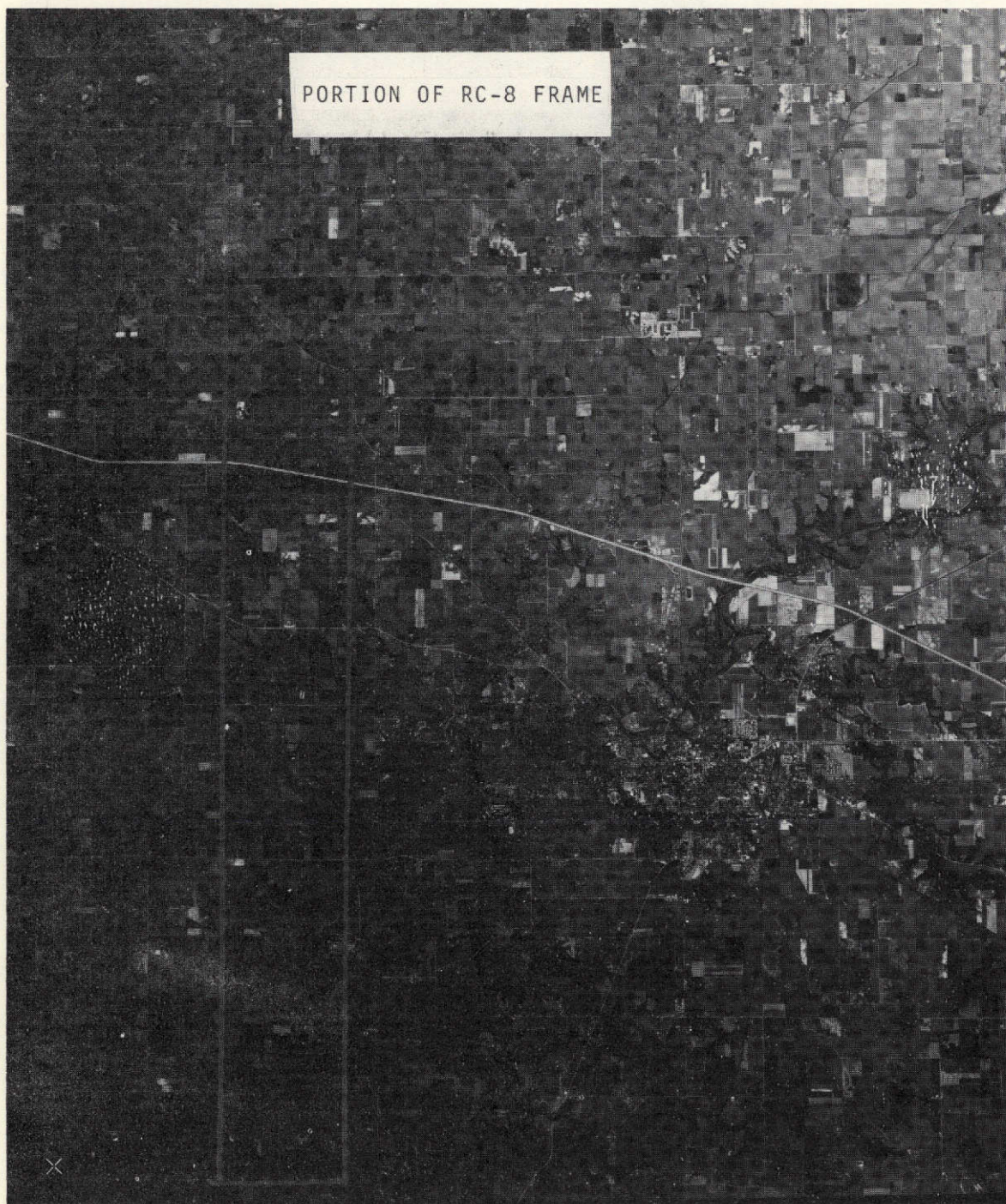


Figure 2.23 — Temporal analysis area in Montgomery County, Indiana.

The test area occupied approximately 4.1 percent of a full 9-by-9-inch RC-8 photo frame. The area (segment 212) is 12 square miles (7,650 acres) and contains 517 fields. The time required to perform the analysis has been estimated for the total ground area covered by an RC-8 frame imaged from 60,000 feet, or approximately 290 square miles. Time estimates have also been projected for Montgomery County. More ambiguous time estimates based on land area (square miles) have been projected for Indiana and the ASCS compliance program within the United States. The accuracy of the temporal analysis is reviewed in the following section:

- Classification Accuracy

Table 2-II summarizes the crop classification accuracies achieved by the two-man interpretation team using a seven-mission temporal look at approximately 500 fields. The interpreters had minimal crop classification experience and only a very brief familiarization with the crop calendar for the Corn Belt region of the United States. Interpretations were made by comparing unknown fields with known training fields imaged sequentially through the summer season.

Analysis of the results indicate that it is technically feasible to perform crop classification from high altitude aerial photography when optimum techniques are used. Errors in this analysis were primarily attributable to:

1. Ground truth terminology as well as erroneous ground truth.

TABLE 2-II.-- TEMPORAL CROP CLASSIFICATION -- SEGMENT 212

Crop Type	Total Number Fields	Number Correct ID's	Crops Confused With	Percent Accuracy	Remarks -- Primary Causes for Errors
Corn	125	123	---	98.4%	Ground truth error and interpreter error
Soybeans	59	54	Pasture, Diverted	91.5%	3 ground truth errors and 2 cases of weak signatures
Oats	25	16	Hay	64.0%	Interpreter errors, influenced by companion crops on later missions
Hay	29	18	Pasture	62.0%	Errors due to late planting, fields not cut, and interpreter errors due to not detecting mowing
Winter Wheat	13	3	Hay	23.0%	Interpreter errors, influenced by companion crop on later missions, May 17-July 16 key signatures
Grain Sorghum	5	4	Winter Wheat	80.0%	Ground truth error, cut before mission 177
Diverted	10	2	Pasture, Winter Wheat	20.0%	Bad category; should have been diverted pasture, diverted -- winter wheat, etc.
Pasture	88	46	Hay, Oats	52.3%	Errors due to fields being mowed in midsummer similar to hay
Woods & Pasture	24	23	Nonfarm	95.8%	Interpreter error (no buildings)
Woods	38	35	Pasture, Hay	92.17%	Errors due to ground truth terminology, no trees -- appears to be weeds, shrubs, and grass
Nonfarm	72	52	Woods	72.27%	Interpreter errors due to failure to note small buildings; also ground truth nomenclature
Others	29	---	---	---	Includes fields whose boundaries were not adequately shown on the base map and field categories "idle, grass and row crop," which were considered ambiguous.

2. Lack of experience in crop identification of some similar crop types, particularly hay, oats, pasture, and winter wheat.

- Verification Accuracy

Although not demonstrated, high altitude photo validation of crop types, compared to the farmer's field identifications, should provide accurate data based on the classification test results.

- Classification Time Estimates

Tables 2-III and 2-IV give the areas and estimated time requirements to perform crop classifications for an RC-8 photo frame, Montgomery County, the State of Indiana, and the total ASCS compliance program. These times are based on the 12 square mile test area which took the two-man interpretation team 19 hours to complete. This works out to approximately 27.2 fields analyzed temporally per hour.

TABLE 2-III.— POTENTIAL CLASSIFICATION AREAS

<u>Area Measured</u>	<u>Area</u>
Segment 212	12 square miles — contains 517 fields 4.1% of an RC-8 frame 2.4% of Montgomery County
RC-8 frame	60,000 feet, 290 square miles
Montgomery County, Indiana	500 square miles
Indiana	36,185 square miles (land area)
United States	3,548,974 square miles (land area)
Corn Belt region, ASCS compliance sampling area	75,000 square miles

TABLE 2-IV.— TIME ESTIMATES FOR CROP CLASSIFICATION

<u>Area</u>	<u>Time</u>
12 square mile area	19 team hours (actual)
RC-8 frame	11.5 team weeks
Montgomery County	20 team weeks
Indiana	27.5 team years
75,000 square miles	57 team years

2.3 DATA MANAGEMENT

Two major areas were studied:

- Requirements for tract location and sensor data registration
- Sensor data volumes and information storage and retrieval requirements

The functional problem of getting data to the county agents was believed to be essentially an ASCS problem and not a technical consideration to be addressed by the study team.

2.3.1 Data Base for Tract Location and Sensor Data Registration

The purpose of this type of data base is to provide an accurate and reliable means for registering MSS data to specific tracts and tract ownership. There are five basic aspects of this data registration/location problem:

- Provide distortion-free imagery with geodetic control.
- Provide digitized photos for automatic registration with either maps or MSS data.
- Develop tract centroids and an identification code compatible with ASCS requirements.
- Establish tract boundary coordinates, where needed, from the primary control.
- Overlay MSS and digitized photos and control points for data registration.

Figure 2.24 shows the flow from photo to automatic registration.

ASCS is presently using uncontrolled photomosaics and unrectified photography for individual farm tracts. These materials are produced on a county-to-county basis with no overall standardization or procedures for periodic update. No grid coordinate system is used, precluding overlaying a control grid on the present best-fit mosaics.

Secondly, there is a map data base available on 1:24,000 topographic maps, which is accurate enough for establishing a data base. However, two problems exist concerning these 1:24,000 scale maps:

- There is incomplete coverage of the U.S.
- Many of the U.S.G.S. maps are not current and have little or no reliable ground detail.

A third major consideration, state-of-the-art feasibility, indicates that it is possible to achieve an accurate data base, although the program has not presently been originated. It is estimated that a complete data base of the 300,000 square miles of the ASCS survey area could be established in approximately 10 years. This data base would include three elements.

- Rectified photos can be compiled into a controlled photomosaic, using conventional geodetic control and resurveying many of the control points to meet the ± 25 meter criteria for point location. The best scale to accomplish the job would be a 1:24,000 scale.

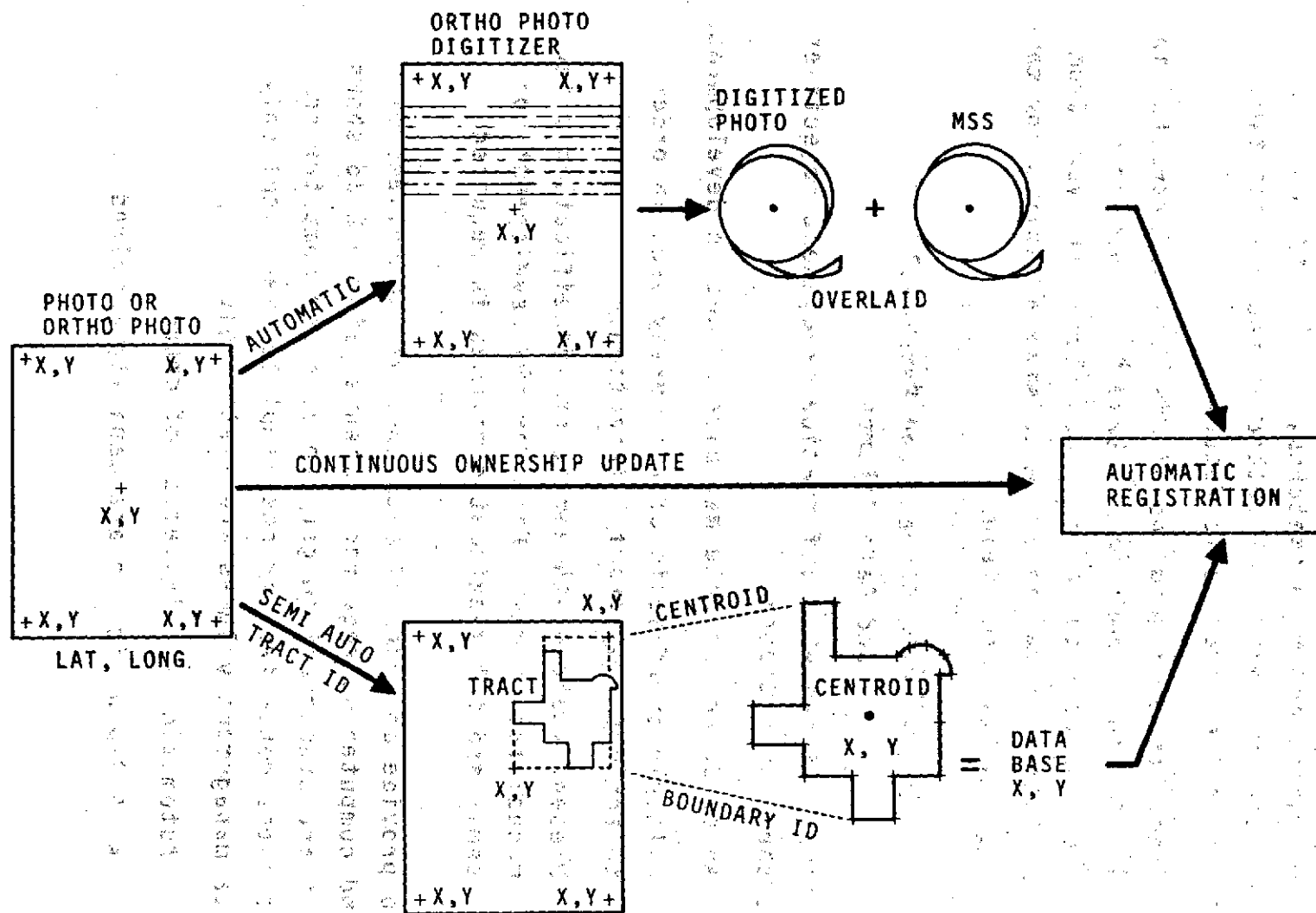


Figure 2.24 - Data registration.

- Upon establishment of a map base, tract boundaries can be manually transferred from ASCS records, such as photos and form sketches, to the map base. This is the only practical method at the present time and in the foreseeable future.
- Tract boundary grid coordinates can be extracted in digital form from the map base. The number of coordinates required for each field will vary from a minimum of two or three to several points for complex, multisided fields.

2.3.2 Data Storage and Retrieval and Data Volumes

Analysis of the ASCS information management objectives require three conditions:

- An existing accurate map base or one in development.
- Multiple overflights of the survey area in order to achieve crop/tract information.
- Present state-of-the-art crop identification using manual techniques. Considerable development for semi- and fully-automatic methods is required.

To provide an order-of-magnitude of the volumes of data and computer storage requirements, figure 2.25 shows aircraft and spacecraft imagery volumes and computer compatible tapes generated for one complete overflight only. The data management volumes are listed below.

1. Automatic classification of crops

- 560 megabit storage capacity required

SENSOR	Alt. (ft)	Approximate System Resolution (ft)	Approximate Ground ID Size (ft)	Single Frame Coverage (Nautical Miles Sq)	No. Frames For 1.762×10^5 Sq N. Miles	Film Rolls	Flight Lines	Computer Compatible Tapes
RC-8 Metric	5 K	1	3	1.2	442,000	1,800	418	None
6" FL, 9"x9" Format	20 K	6	20	4.9	25,700	103	102	
50 LP/MM	60 K	9	40	14.8	2,900	12	34	
250 Frames/Roll								
Zeiss RMK 30/23	5 K	0.5	2	0.8	1,000,000	2,500	836	None
12" FL, 9"x9" Format	20 K	2	6	2.5	100,000	250	201	
75 LP/MM	60 K	5	20	7.4	11,300	26	67	
440 Frames/Roll								
Panoramic	5 K	0.4	1	0.2x1.6	2,520,000	10,100	302	None
12" FL, 120" Scan	20 K	0.8	5	0.6x6.6	163,000	700	76	
2-1/4"x24" Format	60 K	2	10	1.8x20	17,300	70	25	
120 LP/MM 250 Frames								
SI90A, 6 Channels	5 K	0.6	2	0.3	6x7,000,000	17,500	1,670	None
6" FL	20 K	1	3	1.2	6x437,000	1,100	294	
2-1/4"x2-1/4" Format	60 K	6	25	3.7	6x45,200	113	138	
90 LP/MM 400 Frames	235 NM	100	500	88	6 82	1	5	
SI90B Terrain	20 K	1	3	0.8	1,000,000	2,230	626	None
18" FL	60 K	2	8	2.5	80,000	178	180	
4-1/2"x4-1/2" Format	235 NM	42	210	60	175	1	7	
75 LP/MM 450 Frames								
ERTS NSS	5 K	0.4	2	0.3	24,000		1,200	-
0.086 mrad IFOV	60 K	5.2	25	4.4	2,000		80	
11.56" TFOV	465 NM	260	1,300	100	18		3	
4 Channels								177
70-mm Film								
ERTS RAV	5 K	0.3	1	0.3	24,000		1,200	-
	60 K	4.8	24	4.4	2,000		80	
	465 NM	250	1,200	100	18		3	
								177
SI92 MSS	5 K	1	3	0.1	-		3,510	-
0.182 mrad IFOV	20 K	4	12	0.6	-		600	-
10" TFOV	60 K	12	60	1.7	60,000		207	-
13 Channels	235 NM	260	1,300	39.1	111		10	65
RS-7 Scanner	5 K	8	24	2 Swath	220 Strips	7530'	220	140
1.5 mrad IFOV	20 K	30	120	8 Swath	56 Strips	500'	56	39
100" TFOV	60 K	90	450	24 Swath	18 Strips	52'	18	13
70-mm								
MSS 24 Channel	5 K	10	50	1.4 Swath	314 Strips	8000'	314	450
2 mrad IFOV	20 K	40	200	5.5 Swath	80 Strips	700'	80	120
80" TFOV	60 K	120	600	16.6 Swath	27 Strips	75'	27	39
RS-14 Scanner	5 K	5	20	1.4 Swath	314 Strips	1000'		180
1 mrad IFOV	20 K	20	180	5.5 Swath	80 Strips	550'		45
80" TFOV	60 K	60	240	16.6 Swath	27 Strips	52'		15

REPRODUCIBILITY OF THE
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Figure 2.25 - Basic sensor parameters and data output volumes for surveying ASCS areas.

2. Crop acreage mensuration and automatic correlation of acreages to tract and tract ownership
 - Map base required
 - Three to five times the present 1108 core storage (160,000 bits) required for a single coverage
3. Data update
 - For every 2 years of the 10-year ASCS program, 1108 core storage will double.

In general, the gross analysis indicates that both a data base and a data management system are well within the state-of-the-art technologically. Cost and personnel resources will be the major factor in this ASCS subsystem.

3.0 DISCUSSION

3.1 CONCLUSIONS

The consensus among the study group is that the basic ASCS Automatic Remote Sensing/Compliance requirements can be accomplished by 1980.

3.1.1 Data Acquisition

The data acquisition subsystem feasibility analysis was devoted to remote sensors, remote data recording systems, and platforms. The objectives desired by ASCS for data acquisition sensors dictate sufficient spectral information for crop and land-use classification, sufficient spatial resolution for acreage measurements, and sufficient geometric fidelity for registration and correlation. The data recording system must keep pace with the output rates of the sensors. The platforms must navigate within acceptable limits and house the sensors and recording systems.

It was concluded that the objectives of the ASCS project can be met by using a combination of state-of-the-art sensors, data recording systems, and platforms. For instance, the ERTS-1 MSS, its data recording system, and a mapping camera on board an RB-57 at high altitude could be used as a prototype to demonstrate technology.

The ASCS could build a scanner for its operational system by the early 1980's with a small enough instantaneous field of view (IFOV) and a large enough total field of view (TFOV) to be used on board high altitude aircraft. The prospect of developing an MSS for spacecraft, which would

satisfy ASCS requirements within the proposed time frame, does not appear promising. It is much more probable that a multiband camera system for spacecraft could be built, but it is not yet known whether the photography would possess sufficient spectral range. Data recording techniques are sufficiently well developed to meet the ASCS data acquisition requirements.

3.1.2 Data Processing

An operational remote sensing system using interactive and manual techniques can be developed to satisfy ASCS requirements. The large amounts of digital data to be processed makes it improbable that the existing general purpose digital computer will be able to process the required data in a timely or cost-effective manner. Parallel-digital computers appear to be the best choice for ASCS applications. The hybrid computer system is potentially the fastest system, but it suffers from a lack of developed techniques for processing remote sensing data.

Techniques for digital imagery correlation/registration require a major effort to be made operational, especially from a computer processing time standpoint.

Training sample selection and feature selection techniques are not adequate to meet ASCS requirements at this time. The outlook for progress in these areas is promising, and it should be possible to meet ASCS requirements by 1980.

The Gaussian maximum likelihood classifier is an effective technique for pattern recognition. With the

availability of temporal information, better preprocessing techniques (such as atmospheric corrections), and better training field selection and feature selection techniques, the Gaussian maximum likelihood classifier should be able to meet ASCS requirements in an operational system. A strong contender is the per-field classifier, but improvements in the overall accuracy and speed achievable with per-field classification cannot be exploited until a completely automatic field boundary detection technique is developed. Existing automatic boundary detection techniques are presently not adequate to meet ASCS requirements.

In spite of human error problems, semiautomatic and manual techniques for crop classification and field measurements are sufficiently accurate, though time consuming.

3.1.3 Data Management

Semiautomatic and manual techniques exist or can be developed to establish a data base for tract location and data registration. The data base can be updated on a periodic basis, without redesigning the entire system.

Data storage and retrieval information systems, similar to the HATS RIMS, can be developed within the stated time frame.

Sensor data volumes, both photographic film and digital tapes, are not excessive for establishing a viable data bank.

3.2 RECOMMENDATIONS

Recommendations regarding the ASCS project involve three interrelated phases:

- Phase I — Expand the results of this study giving a more detailed technical and cost benefit systems analysis of the major subsystems.
- Phase II — Integrate the results of Phase I with the user requirements and suggest a prototype system.
- Phase III — Develop and begin testing the prototype system against the user requirements.

3.2.1 Data Acquisition

The data acquisition subjects recommended for further research are primarily concerned with the sensors necessary for the ASCS project. Data recording system technology is rapidly advancing and is nearly sufficient. Platform technology seems adequate. In general, the state of military data acquisition technology, some of which is classified, should be reviewed.

The question of appropriate sensors hinges upon several factors; namely, sufficient spectral range and sensitivity for crop and land-use classification, sufficient spatial resolution for accurate acreage measurements, and sufficient geometric fidelity for data registration. If multiband photographic systems possess sufficient spectral range, they might be more feasible than multispectral scanners for both high-altitude and spacecraft applications. This question needs serious consideration. Also, the problem of recording and transmitting conventional camera film data, particularly

digitizing and transmitting multispectral imagery from spacecraft, needs further research.

Multispectral scanners should not be ruled out as sensor candidates for spacecraft applications, but sensor design criteria, data recording technology, and channel selection need investigation.

The problem of appropriate sensor resolution for the ASCS project is not yet resolved. Its impact upon the whole data acquisition system dictates extensive theoretical as well as practical evaluation.

3.2.2 Data Processing

The areas of data preprocessing, such as atmospheric corrections, sun angle corrections, scan angle corrections, and photo rectification, require additional investigation.

It is recommended that a data processing system consisting of automatic, interactive (man-in-the-loop), and manual techniques should be used to meet ASCS data processing requirements. Bench tests should be conducted on a parallel digital computer and a hybrid computer to evaluate their effectiveness in meeting these requirements.

Training sample selection and the use of photointerpretation techniques in training field selection should be further investigated. Better procedures for collecting ground truth and a good clustering technique are required.

A feature selection technique based on the probability of error of misclassification or closely related techniques

should be developed. Feature subset search procedures require additional investigation also. A potentially significant contribution to the feature selection problem, particularly in temporal pattern recognition, can be made by the development of good crop calendars for the Corn Belt. A good crop calendar can reduce many of the problems in feature selection by permitting coverage of the Corn Belt when crops are most readily discriminated.

Pattern recognition also needs further investigation. This includes the Gaussian maximum likelihood classifier, the per-field classifier, and the use of temporal information in pattern recognition. Procedures for manual photographic crop identification techniques require additional research.

The field boundary location problem includes both automatic and manual techniques for boundary location. The relationship between resolution element size and boundary location accuracy needs to be established. Also, qualified techniques need to be established for both automated and manual mensuration.

3.2.3. Data Management

System requirements need to be set up for a prototype inventory data management system, similar in nature to the present RIMS. The system must meet ASCS information storage, retrieval, and dissemination requirements. An in-depth survey of existing federal and state information management systems should be made to determine the best possible system to be conducted for ASCS.

3.2.4 SR&T and In-House MSC Research and Development (R&D) Programs

It is recommended that MSC carefully coordinate and integrate the system analysis of Phase I with the present SR&T and MSC in-house R&D programs now being conducted by NASA/MSC Science and Applications Directorate and in-house R&D. The current SR&T projects include the following:

- Data Collection

- Atmospheric effects (University of Michigan and MSC/EOD)

- Signature extension (University of Michigan)

- Geometric corrections for cartographic and mensuration (University of Michigan and MSC)

- Data registration (Purdue University and MSC)

- Data Analysis

- Spatial pattern recognition (Colorado State University and MSC/EOD)

- Multielement classification (Purdue University and University of Michigan)

- Adaptive classification (Purdue University and University of Michigan)

- Special techniques for recognition enhancement (University of Michigan)

- Estimating proportions of unresolved objects in remote MSS data (University of Michigan)

- Spectral class-subclass definition (Purdue University and MSC)

Investigation of the precision of remote sensing estimates (Purdue University)

Improvement in interactive methods (Purdue University and MSC)

Applied Mathematics in classification analysis (University of Houston)

Earth resources data analysis program (Rice University)

Evaluation of techniques for analysis of remote sensing data (University of Texas-Dallas)

- Information Management

Socioeconomic analysis (Purdue University)

- Crop Productivity

Investigation (Purdue University)

Delineation of stressed and healthy vegetation (Purdue University)

Specialized field data instrumentation (Purdue University)

- Soil Type

Soil survey (Purdue University)

Spectral properties of soils (Purdue University)

- Soil Moisture

Radar measurements of soil moisture (University of Kansas)

Development of a soil moisture probe (Purdue University)

- Geology
 - Radar geological features analysis (University of Kansas)
- Advanced Studies and Planning
 - Multifrequency radar (University of Michigan)
 - Passive MW radiometer (Jet Propulsion Laboratory)
 - LARS computational facility (Purdue University)
 - Severe storm environment (University of Oklahoma)
 - Multispectral scanner performance (University of Michigan)

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